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Ecological Monitoring Program at VIMS ESL - Annual Report 2018-2019

Paige G. Ross
Virginia Institute of Marine Science

Richard A. Synder
Virginia Institute of Marine Science

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Paige G. Ross and Richard A. Snyder, Eds.

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

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Contents

2018-2019 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 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 scientists' 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 combined with marine operations and shore support provided by VIMS ESL. The 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 clam, scallop and oyster aquaculture, bay scallop restoration, and shorter-term grant supported research projects are reported elsewhere.

Our 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 condition of seaside oyster populations, combining historical records with ongoing assessment. In 2019, annual cumulative spat set as high as 62,000 oysters per m^2 was recorded. Overall 2018 was an average settlement year, and 2019 a bit above average. Benchmarks for adult oyster population demographics were established. The epi-benthic communities of soft-sediment, intertidal oyster reefs and subtidal shell beds were described based on data gathered from >7,000 individual organisms representing ~ 90 genera. Substantial change in the vicinity of Wachapreague Inlet was documented based on yearly aerial drone surveys encompassing ~190 hectares of island/marsh and ~16,600 m of shoreline. Aerial drone near-infrared surveys continued in an area of marsh dieback (~30 hectares) and will contribute to determining whether this area is continuing to expand, recovering, or has reached some form of stasis. Characterization of sediments at 108 and 93 sites during 2018 and 2019, respectively will set a baseline for determining future changes, especially with regard to carbon storage in this productive and organic rich coastal marine ecosystem.

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. 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

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

The VIMS ESL mission is to serve as a field station and coastal seawater laboratory for visiting and resident 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 environmental status and trends for this predominantly unspoiled coastal region
3. Engage interns and students in rigorous technical scientific training while they contribute to a larger long-term effort.

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*. 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 creek, 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 seawater and habitats adjacent to the laboratory, including leased bottom maintained specifically for research purposes.

The VIMS ESL, as a launch point for diverse resident and visiting research, 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. 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 and longer-term environmental change.

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 and 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 mangement 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 our 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. Facilitate capacity building

    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 student 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

Authors: PG Ross & Richard A Snyder
Virginia Institute of Marine Science, Eastern Shore Laboratory, Wachapreague, VA

2018 & 2019 Metrics

The EMP framework was designed to collect status and trends environmental and ecological data near the Eastern Shore Laboratory. Table 1-1 provides a list of data collected during 2018 & 2019. 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 cumulative 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

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.

Component	2018 Yr 1	2019 Yr 2	2020 Yr 3	2021 Yr 4	2022 Yr 5	2023 Yr 6	2024 Yr 7	2025 Yr 8	2026 Yr 9	2027 Yr 10
Oyster settlement	X	X	X	X	X	X	X	X	X	X
Oyster disease (Dr. Ryan Carnegie)	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* (SOM & fract. 5 cm interval)	X	X		X		X		X		X
Sediment mapping: *full grid* (surficial SOM/Chla; SOM/fract. 5 cm interval)				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	

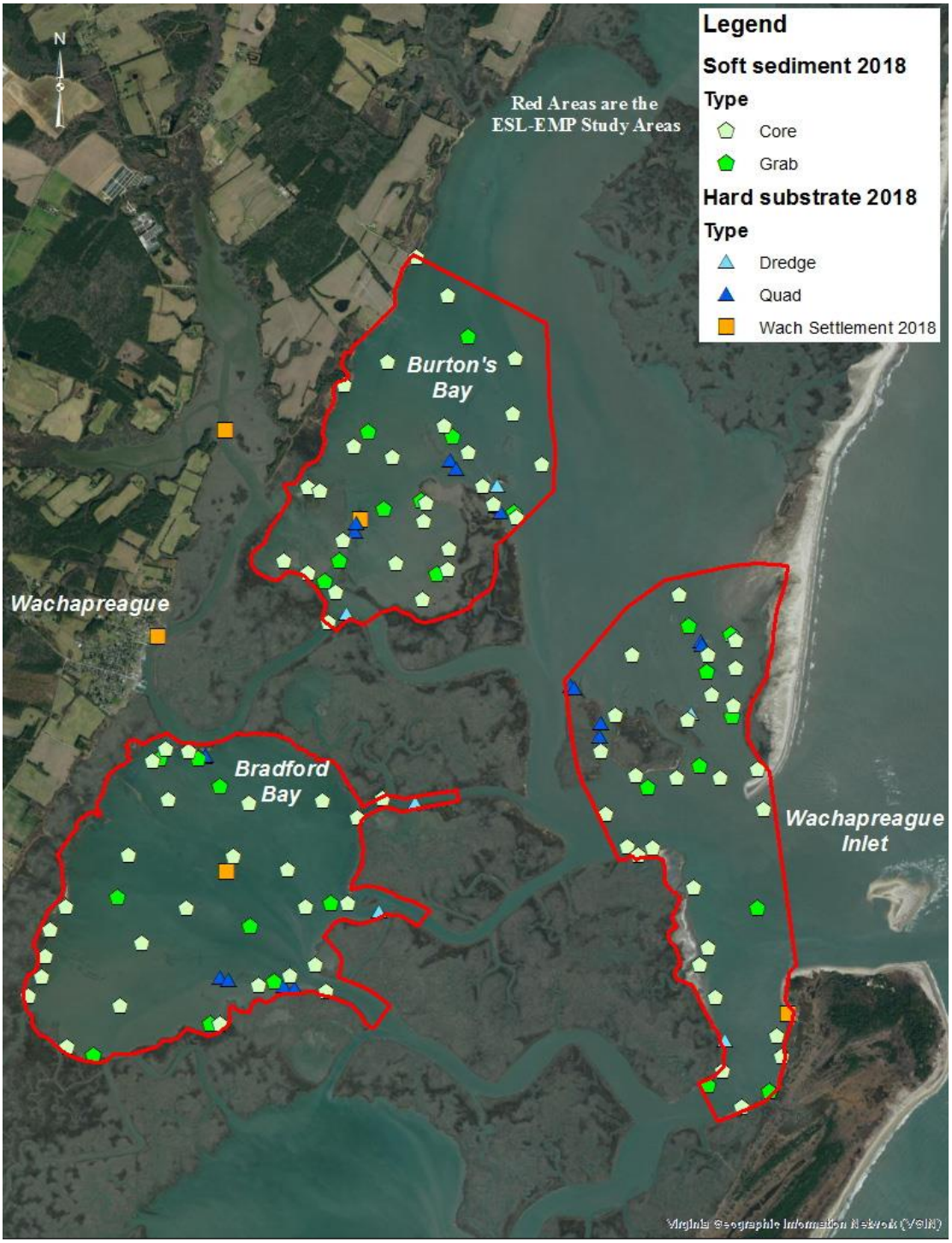

Fig. 1-1 Three geographic regions of the ESL-EMP with some sampling locations from 2018: Bradford Bay (relatively stable, but adjacent to uplands); a portion of Burton's Bay (anecdotal signs of some current changes) and the Wachapreague Inlet vicinity (very dynamic).

Chapter 2. Water Quality

Section 2-1: Fixed Sensors (continuous)

Authors: Darian Kelley, PG Ross and Richard A Snyder

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

5-year sampling plan:

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

Introduction

The VIMS-Eastern Shore Laboratory (ESL) has established and maintains continuously recording, fixed-sensor, water quality stations at the three locations (Fig. 2-1-1) using YSI (now Xylem) Exo 2 datadsondes:

- Wachapreague (37°36’27.80’’ N 75°41’08.93’’ W) *RA Snyder VIMS startup funds*
- Custis Channel (37°36’58.77’’ N 75°39’50.50’’ 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. These water quality data can also be utilized to inform coastal zone management decisions.

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. Home of the largest hard clam aquaculture production in the country, the Eastern Shore’s multimillion-dollar commercial shellfish industry is important both economically and environmentally. With funding from a private donation (Steve and Barbara Johnsen) and site support from Cherrystone Aquafarms, a station was established in Willis Wharf, VA, home to three major hatchery operations. Real-time and archived data are used daily by these operations, as well as regional aquaculturists and fishermen to monitor current water conditions. The 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 from the Wachapreague and Willis Wharf stations can be found at www.vims.edu/esl/research/water_quality/. Archived data for all three 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 flow cell chamber where the water sample is analyzed. The data are reported via a live telemetry and control system provided by Green Eyes, LLC (Cambridge, MD). This 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.

The Custis Channel water quality station, established in June 2016, is positioned adjacent to a VIMS shellfish lease in the southeastern portion of Burton's Bay. This area is utilized for studies involving oysters, oyster disease monitoring, and other oyster reef related work. This remote and un-telemetered station is submerged at a fixed depth ~1ft above the bottom. Since this station is fully submerged, regular maintenance is required to address biofouling. Drawbacks to this type of setup include relying on batteries to power equipment, retrieval of equipment by boat, having to manually recover data after retrieval, and loss of equipment due to the unprotected nature of the site to storm damage, especially during fall and winter months.

Maintenance schedules vary depending on season, station setup, 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 intake lines. 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 are constantly exposed to the marine environment, flow cell and sensor maintenance are minimal. Light cleaning of the flow cell wall occurs once a month. The submerged station at Custis Channel requires complete equipment recovery for cleaning and data retrieval biweekly in the warm summer/fall months, and monthly in the cooler spring/winter months. To minimize any gaps in the datasets, deployed equipment is immediately swapped with a clean, calibrated datasonde.

Data for eight water quality parameters are collected at each station (Table 2-1-2). 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 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.

2018 and 2019 Results

Water quality data was collected at all three stations during portions of 2018 and 2019. However, full year coverage was hampered by severe weather causing structural failures and software and hardware hurdles that required extensive troubleshooting. Minimums, maximums and averages for temperature, salinity, pH, dissolved oxygen, turbidity, chlorophyll, and blue green algae are summarized in Tables 2-1-2 through 2-1-4 for time periods where six or more months of data was collected. Although they may cover different time periods for the three sites, there is some overlap and these data 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 results for combinations of stations and parameters for 2018 and 2019. 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 noticeable across all ESL stations (Figs. 2-1-2 & 2-1-5). Episodic events are

also seen (e.g. significant salinity troughs during July and Sept 2018 for the Custis Channel station; 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 all three stations is available upon request.

Comparison to Previous Years

Although the EMP formally started in 2018, water quality data has been collected from Wachapreague and Custis Channel since 2016. Combining these data allows >2 years of data to be visualized and compared for specific metrics (e.g. see Fig. 2-1-9). There are several examples of how these yearly comparisons may be useful. First, in Fig. 2-1-9, the circled area labeled "A" shows some distinct yearly differences in salinity during April, which may be of interest to local shellfish hatcheries active during those times. Second, in the same figure, the area labelled "B" shows 2 very noticeable episodic events in September and October 2016 where salinity plummeted for short durations. As one would expect, these anomalies correlate well with overall climate variability and significant rainfall events (see Fig. 2-1-10).

Water temperature data from ESL's Wachapreague station was compared to NOAA's WAHV2 station for 2016. Archived NOAA temperature data was subjected to the QAQC process discussed above. Average daily water temperatures were calculated for days when >85% of expected readings were captured for both stations (n=204 days). The difference in daily averages between the two stations (WT_{ESL}-WT_{NOAA}) is shown in Figure 2-1-11, with an average daily variation of 0.14 °C ± 0.17 °C. This positive value and the distribution of points above the line in Figure 2-1-11 indicates that the WT_{ESL} recordings tend to be higher than the WT_{NOAA} recordings. This discrepancy is likely due to the WT_{NOAA} sensor being fixed and subject to submersion to deeper water at high tide, whereas the pump inlet for WT_{ESL} is on a floating platform and remains consistently in the surface layer of water. When comparing daily paired temperature values (WT_{ESL},WT_{NOAA}), a very tight fit is apparent and an R^2 value of 0.9994 confirms a strong similarity between the datasets (Fig. 2-1-12). Since the water temperature readings are so similar to one another, historical water temperature data from NOAA's WAHV2 station can be used as background context for current and future EMP temperature comparisons.

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.

Discussion

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. Because of this, salinity depressions from rain events are quickly dissipated (Fig. 2-1-10). Additionally, benthic resuspension from tidal flow strongly affects the turbidity signal. Averaging turbidity levels from specific stages during the tidal cycle, reveals the correlation between turbidity and tide in the Wachapreague Channel (Fig. 2-1-13). Data from 2017 reveals the Wachapreague Channel is most turbid 2 hours before low tide, and least turbid at high tide. As the tide is receding, water is being pulled from inside the creeks and estuaries out to the ocean, bringing high volumes of suspended sediment and particles from land. As low tide approaches, the high volume of suspended particles begins to settle to the bottom of the water column, causing the turbidity to decrease. For a short period of time, when the tide switches from ebb tide to flood tide, the shift in current results in an increase in turbidity. Turbidity then starts to decrease as the tide rises, bringing the ocean water back into the creeks and estuaries. As the tide continues to rise, the suspended solids settle to the bottom of the water column. Turbidity levels continue to decrease, and are lowest at the peak of high tide, until the tide starts to fall again. This turbidity example, demonstrates how the data can be utilized by ESL researchers and local hatcheries to time water collections around times of low turbidity, effectively reducing filtration requirements and minimizing supply cost.

ESL water quality monitoring data has already proved to be a useful tool in providing background information and baseline data about tidal and seasonal fluctuations for multiple researchers. A study performed by a VIMS PhD student (Crear et al. 2019), demonstrates potential environmental impacts on sandbar sharks in the western Atlantic and the Chesapeake Bay when faced with warm and hypoxic conditions. Water quality data for 2017 from the Custis Channel station, a known sandbar shark nursery habitat, revealed a 4.6 C tidal variation in water temperature, and an overall range of 21.3-32.8 C during July and August of 2016 and 2017. Crear's study suggests that areas with increasingly warm, hypoxic water may displace sandbar populations, which could result in significant impacts on lower trophic level species.

Additionally, 2017 water quality data from the Wachapreague station displayed significant tidal variation in pH (7.26-7.77 in one tidal cycle). This information is valuable for research being conducted by Hampton University's Dr. Andrij Horodysky, regarding ocean acidification and the neurosensory biology of red drum. Dr. Horodysky's work will shed light on how fish see, hear, and behave based on pH conditions predicted by ocean acidification. ESL's water quality data suggests local marine animals occasionally experience substantial fluctuations and conditions that are predicted to change more drastically in the future.

Water quality data from Wachapreague, Willis Wharf, and Custis Channel 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.

Acknowledgements

We would like to thank Justin Paul, Glenn Brundage, Chris Bentley, Richard Snyder, Connor Lovett, and Edward Smith for fabrication and field help; Vince Kelly (Green Eyes LLC) and Zach Klinglesmith for system design and software troubleshooting; Adam Miller, John Thomas, and Gary Anderson for networking and telemetry help. 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 8 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 Custis Channel station near Wachapreague, VA during portions of 2018 & 2019.

Location: *Custis Channel*

Time period: *Late June-Dec 2018*

	Min	**Max**	**Avg**	**SD**
Temperature (°C)	2.98	33.20	20.37	8.31
Salinity (psu)	17.53	31.89	29.24	1.61
pH	7.15	8.23	7.85	0.20
Dissolved Oxygen (mg/L)	2.90	11.65	7.11	1.83
Turbidity (NTU)	2.91	191.40	17.18	13.29
Chlorophyll (ug/L)	0.01	59.21	5.66	4.75
Blue Green Algae (ug/L)	0.01	115.19	9.50	7.83

Location: *Custis Channel*

Time period: *Jan-Aug 2019*

	Min	**Max**	**Avg**	**SD**
Temperature (°C)	1.08	33.93	18.82	8.28
Salinity (psu)	x19.79	32.83	28.48	2.29
pH	7.30	8.29	7.85	0.17
Dissolved Oxygen (mg/L)	1.00	12.63	7.35	2.01
Turbidity (NTU)	3.18	1316.14	29.51	65.90
Chlorophyll (ug/L)	0.01	41.50	6.57	5.18
Blue Green Algae (ug/L)	0.51	99.19	15.68	11.01

Table 2-1-3. Summary water quality data for the Wachapreague station at the ESL during a portion of 2019.

Location: *Wachapreague (ESL)*

Time period: *Jan-Sept 2019*

	Min	**Max**	**Avg**	**SD**
Temperature (°C)	3.22	34.93	20.91	8.27
Salinity (psu)	15.07	33.06	29.69	2.46
pH	7.22	8.22	7.75	0.20
Dissolved Oxygen (mg/L)	2.40	12.58	6.88	2.16
Turbidity (NTU)	2.74	134.84	17.87	10.51
Chlorophyll (ug/L)	0.28	49.70	7.23	5.63
Blue Green Algae (ug/L)	0.54	96.32	11.03	9.02

Table 2-1-4. Summary water quality data for the Willis Wharf station seaward of the Eastern Shore of Virginia during a portion of 2019.

Location: *Willis Wharf*

Time period: *Jan-Dec 2019*

	Min	**Max**	**Avg**	**SD**
Temperature (°C)	0.15	35.34	18.31	8.68
Salinity (psu)	16.04	33.53	28.70	3.55
pH	7.27	8.47	7.89	0.17
Dissolved Oxygen (mg/L)	2.20	13.60	7.33	2.06
Turbidity (NTU)	2.70	77.05	13.84	7.55
Chlorophyll (ug/L)	0.61	73.13	9.33	6.74
Blue Green Algae (ug/L)	1.12	124.17	16.55	11.43

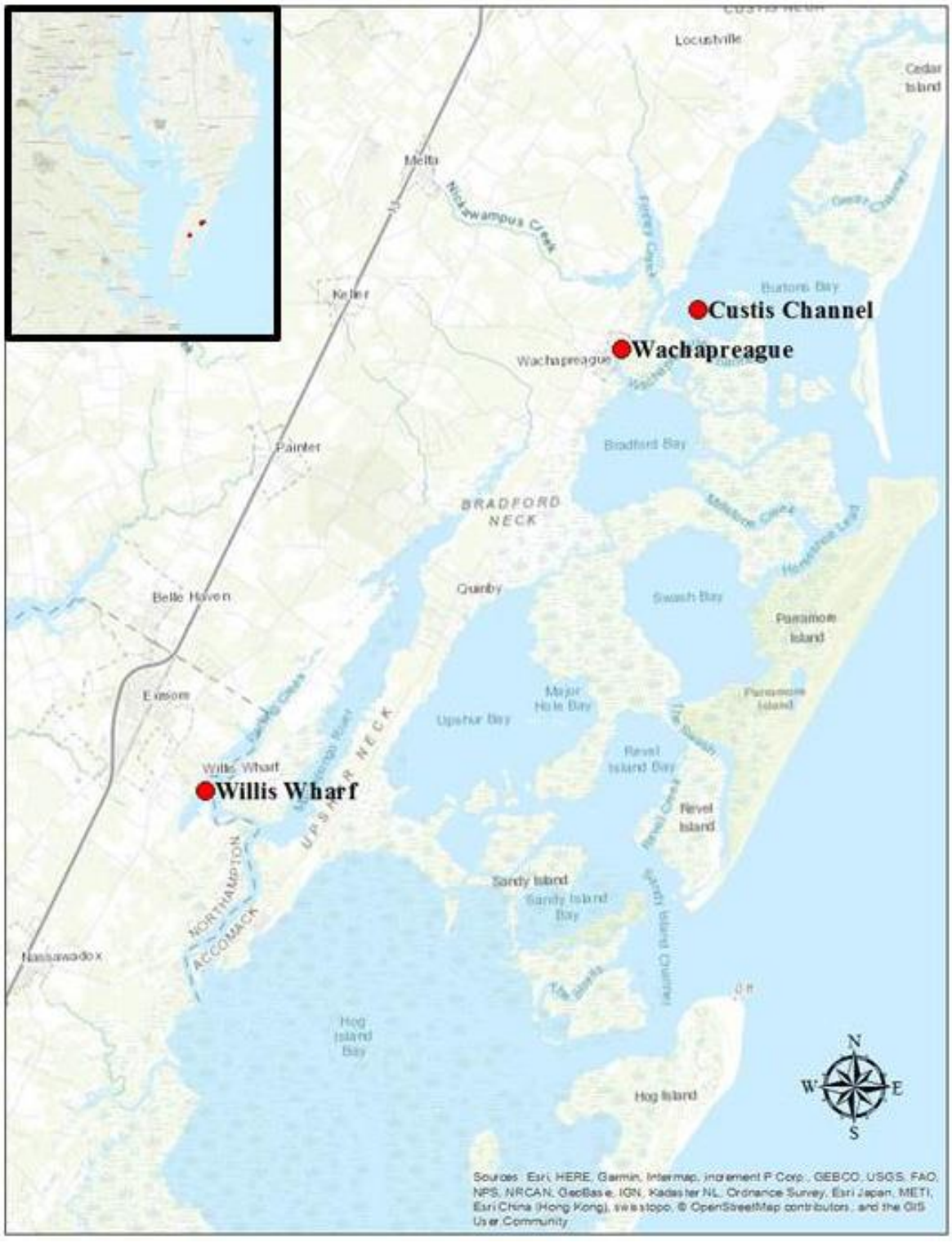


Fig. 2-1-1 Location of three stations equipped with fixed water quality sensors on the seaside of the Eastern Shore of Virginia.

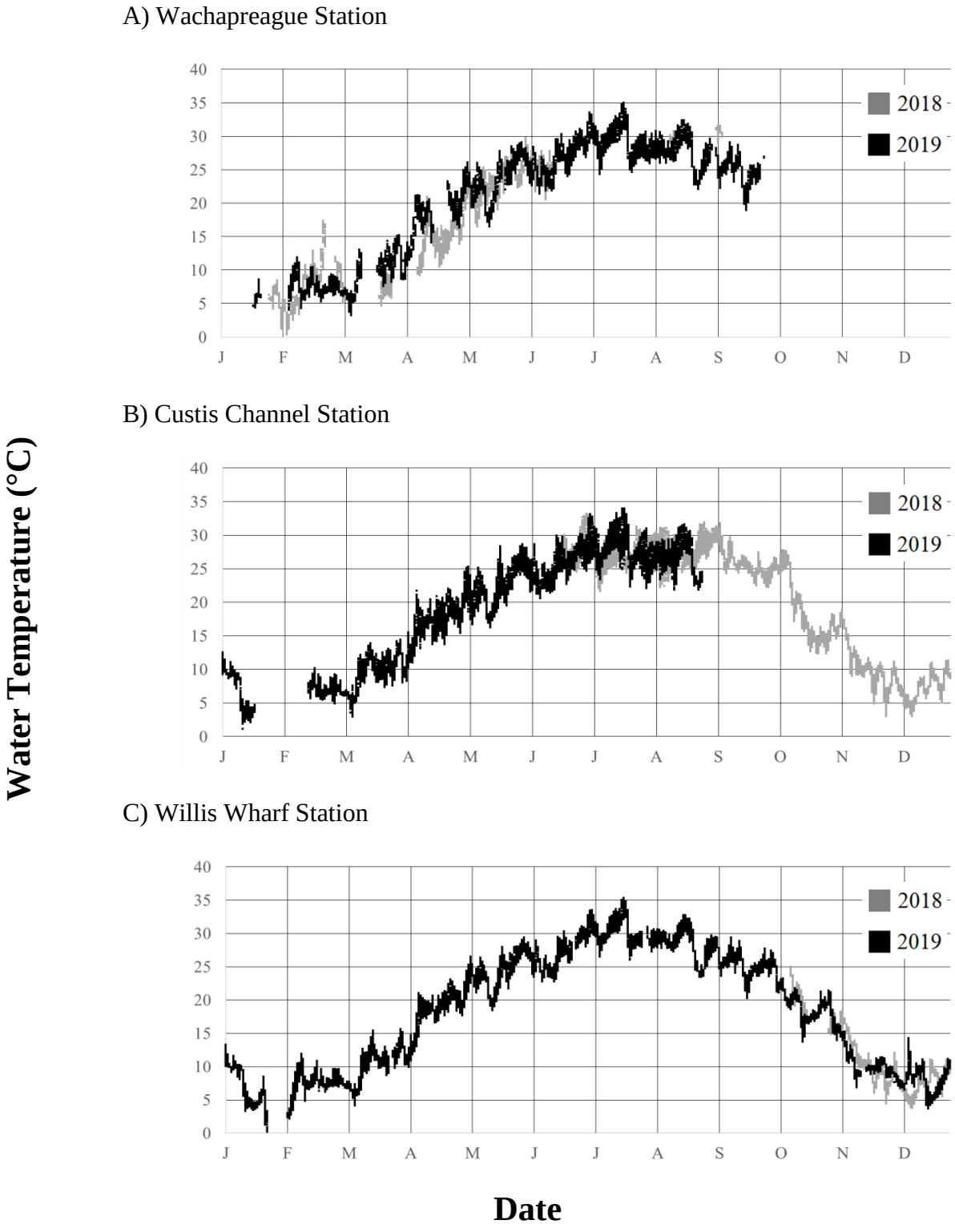


Fig. 2-1-2 Water temperature (°C) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

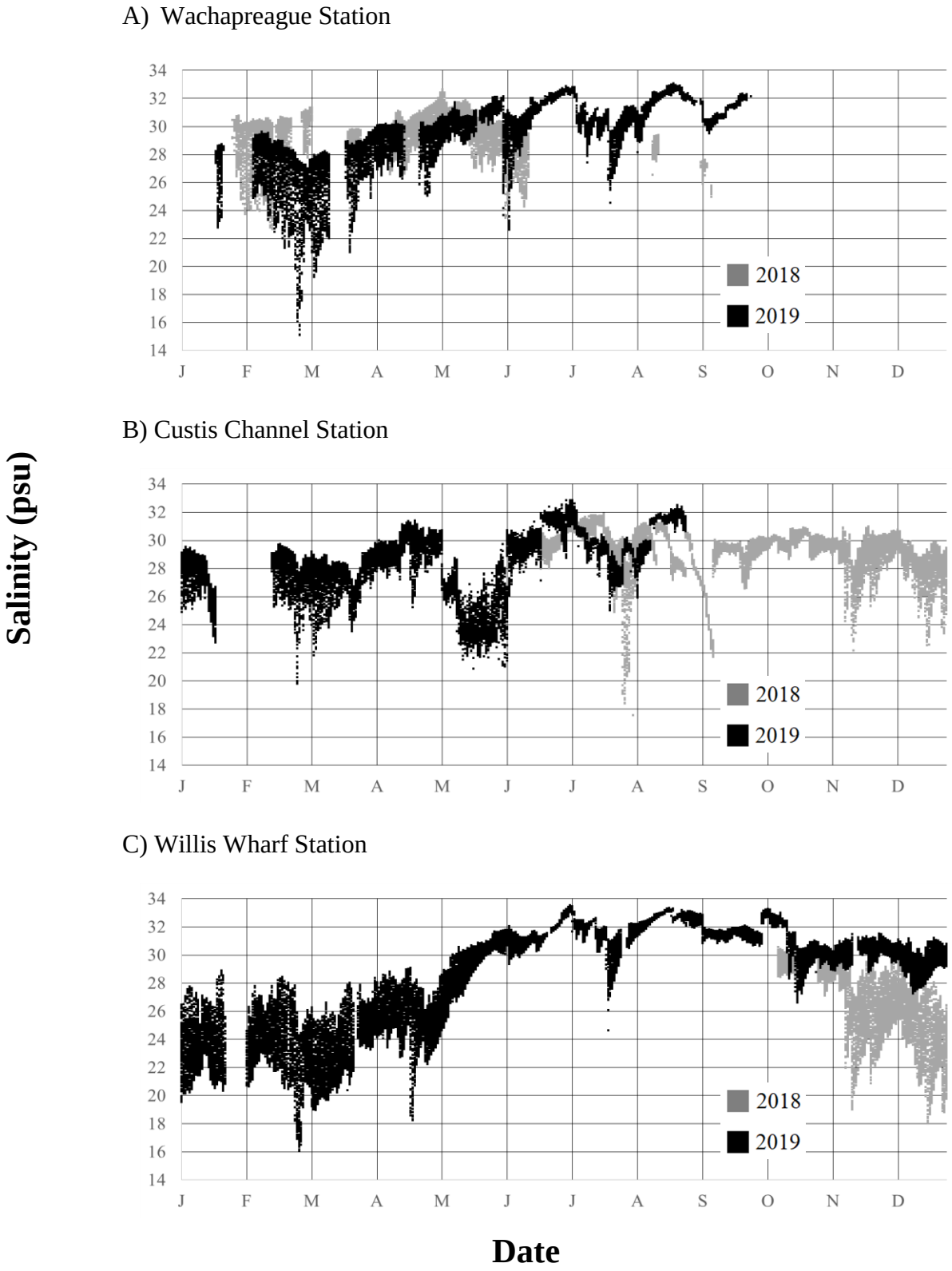
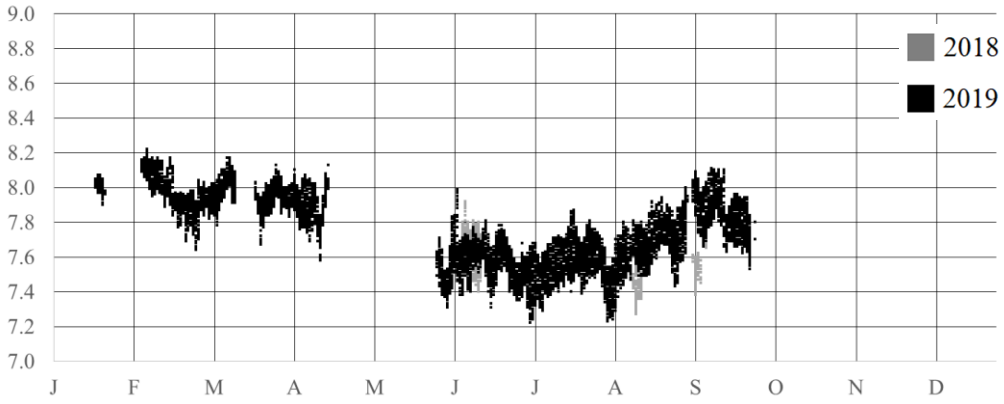
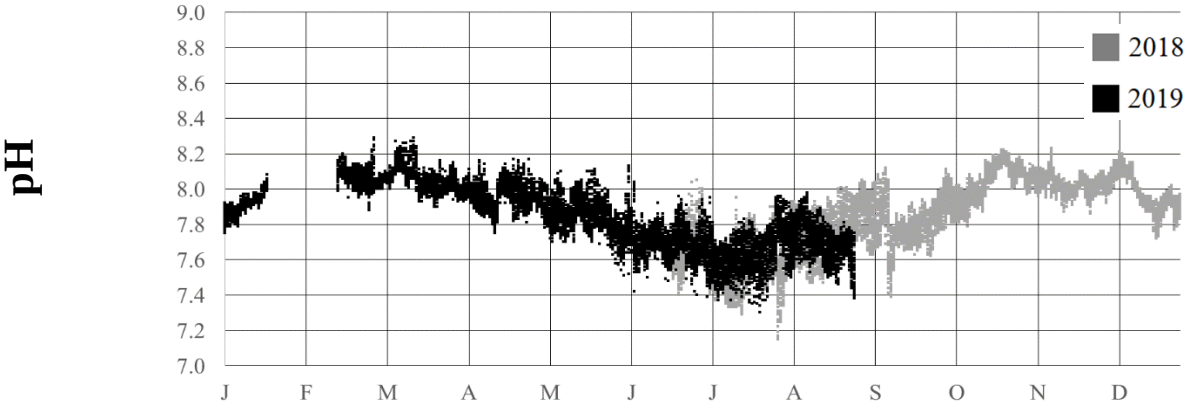


Fig. 2-1-3 Salinity (psu) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

A) Wachapreague Station



B) Custis Channel Station



C) Willis Wharf Station

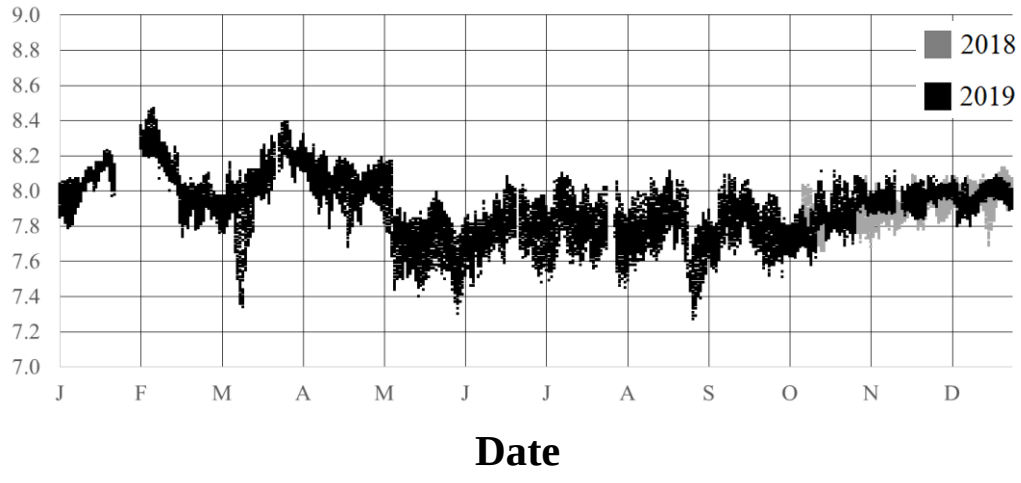


Fig. 2-1-4 Water pH (0-14 scale) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

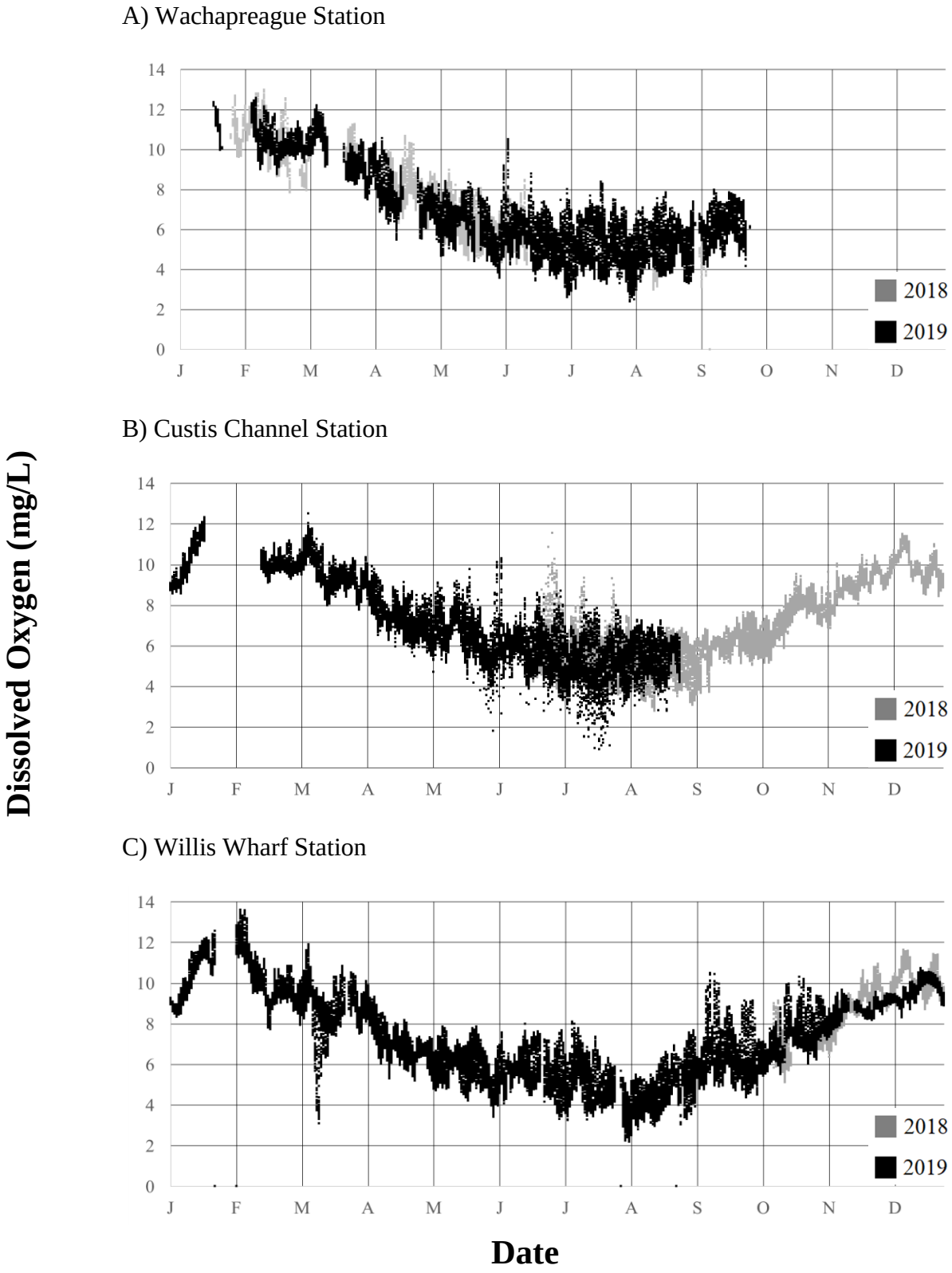


Fig. 2-1-5 Dissolved oxygen (mg/L) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

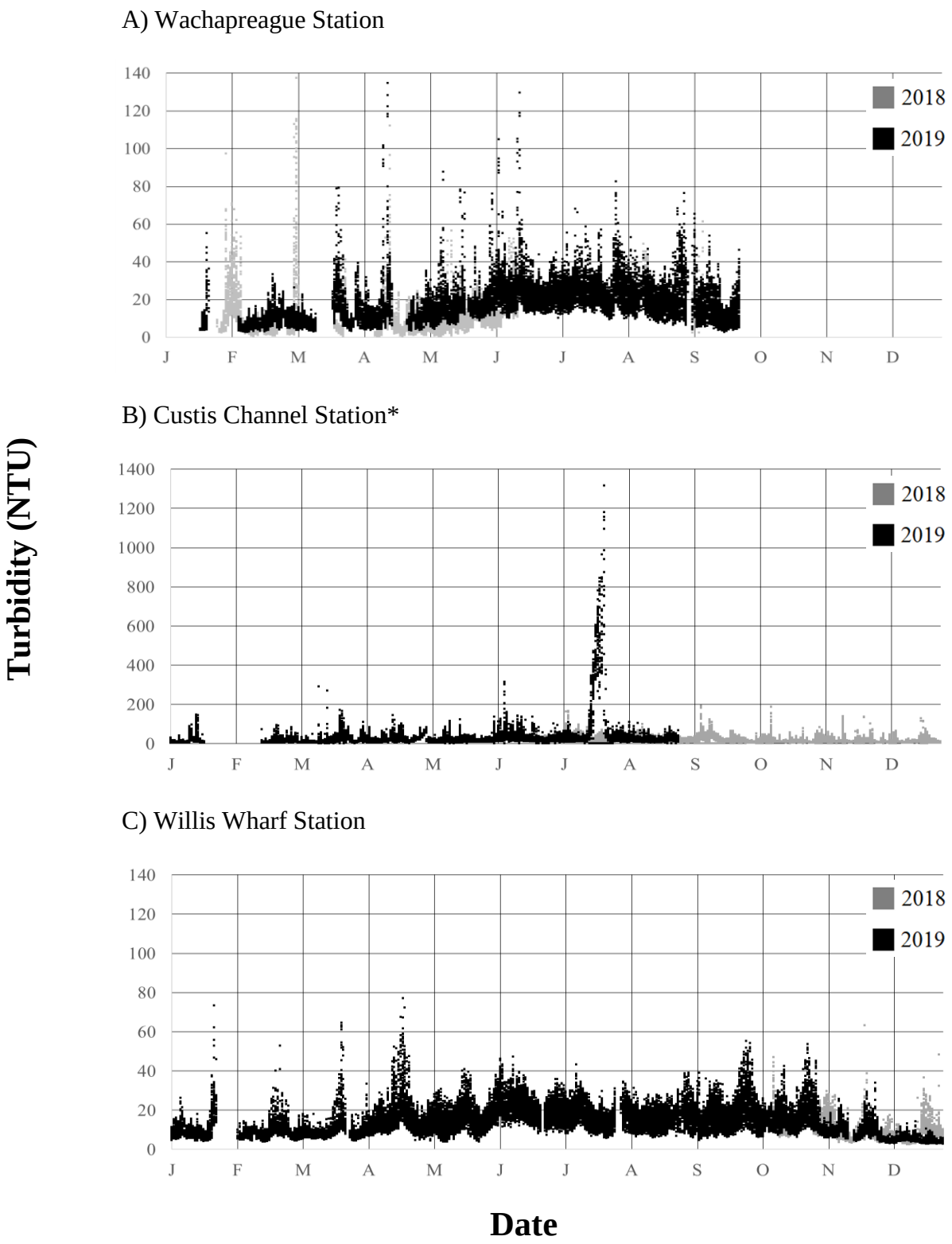


Fig. 2-1-6 Turbidity (NTU) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black). **Note that the vertical scales for A & C go to 140 NTU, whereas B is an order of magnitude higher at 1,400 NTU.*

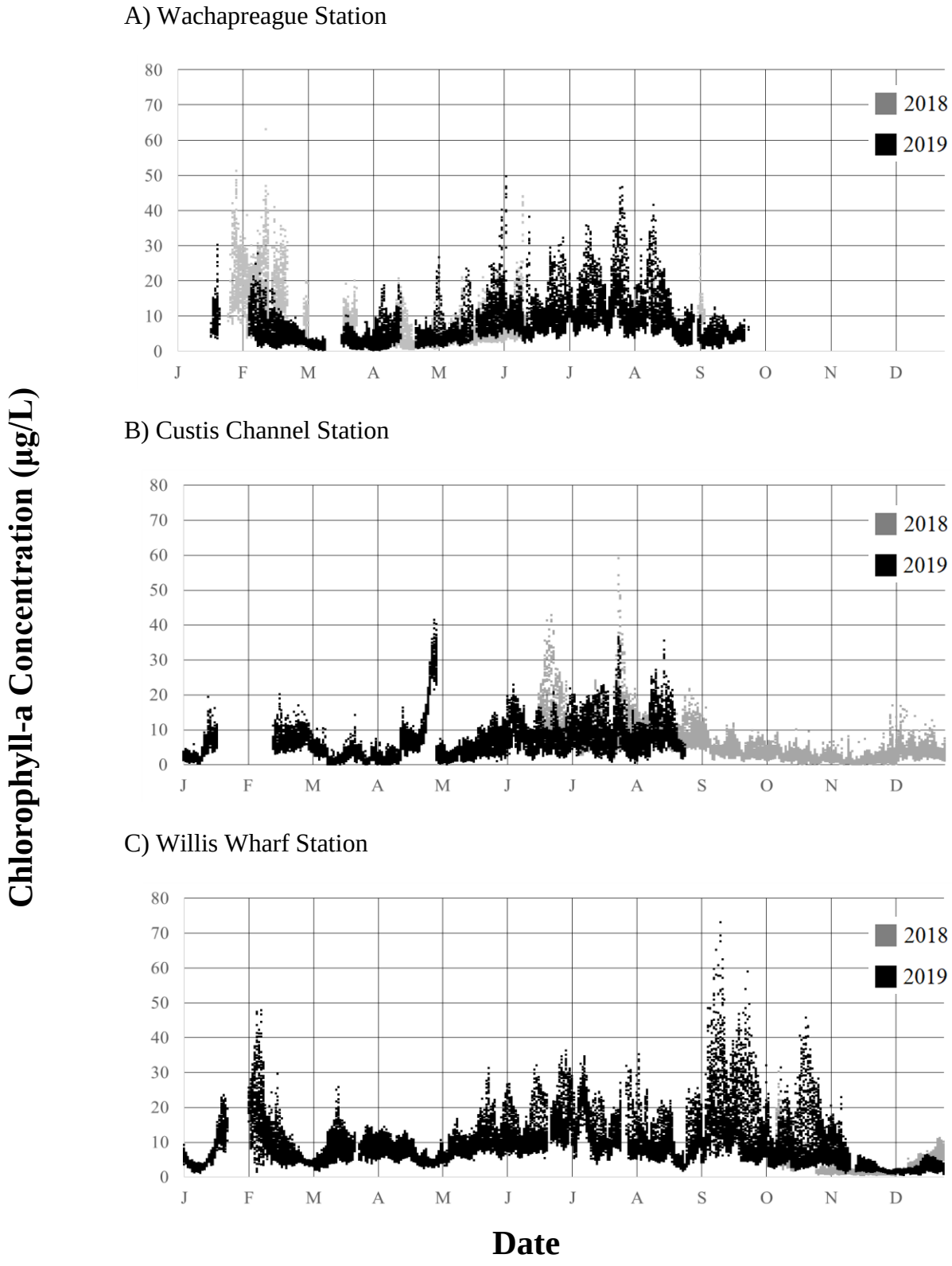


Fig. 2-1-7 Chlorophyll-a concentration (µg/L) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

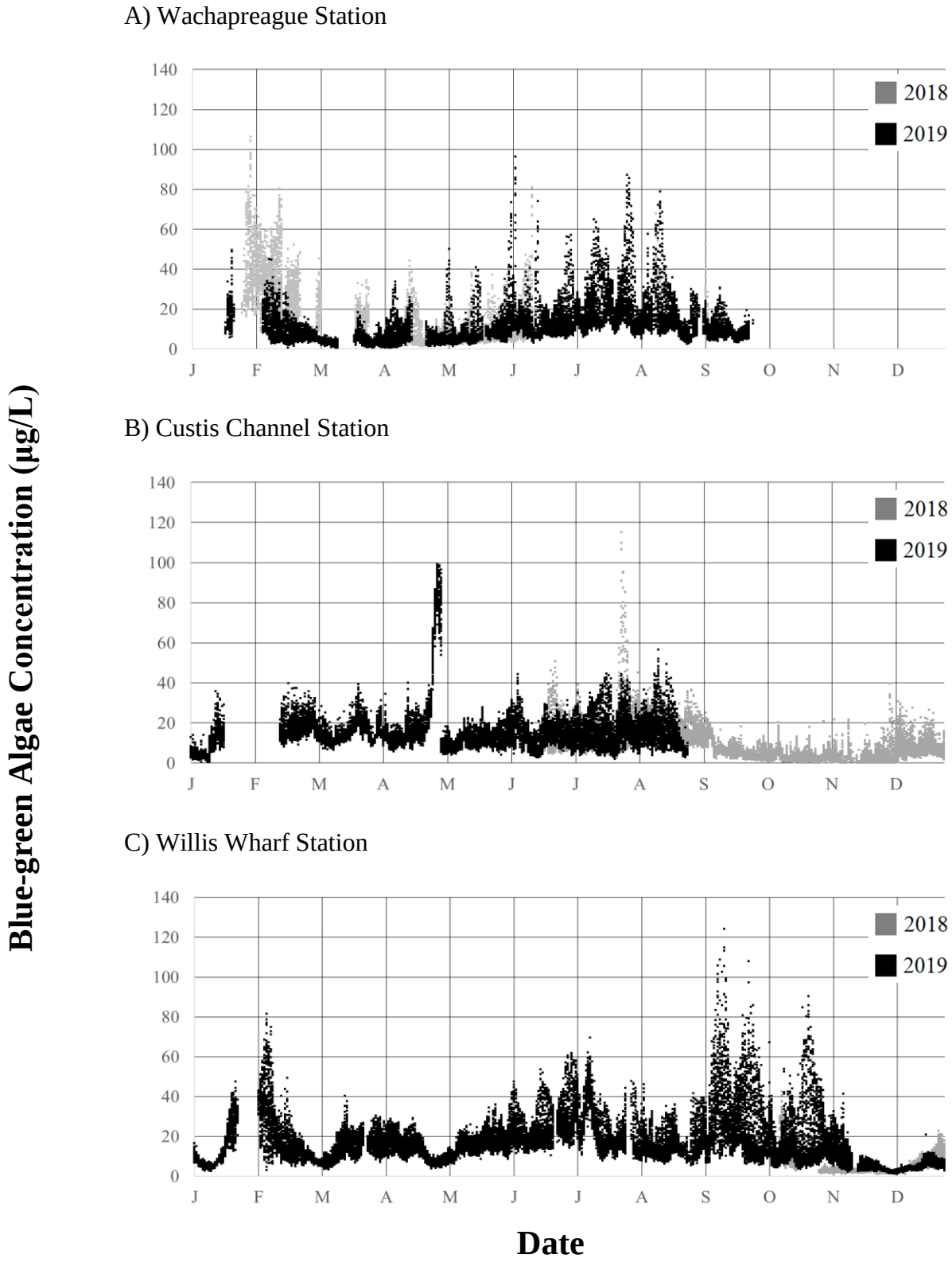


Fig. 2-1-8 Blue-green algae concentration (µg/L) for the A) Wachapreague, B) Custis Channel, and C) Willis Wharf water quality stations during 2018 (gray) and 2019 (black).

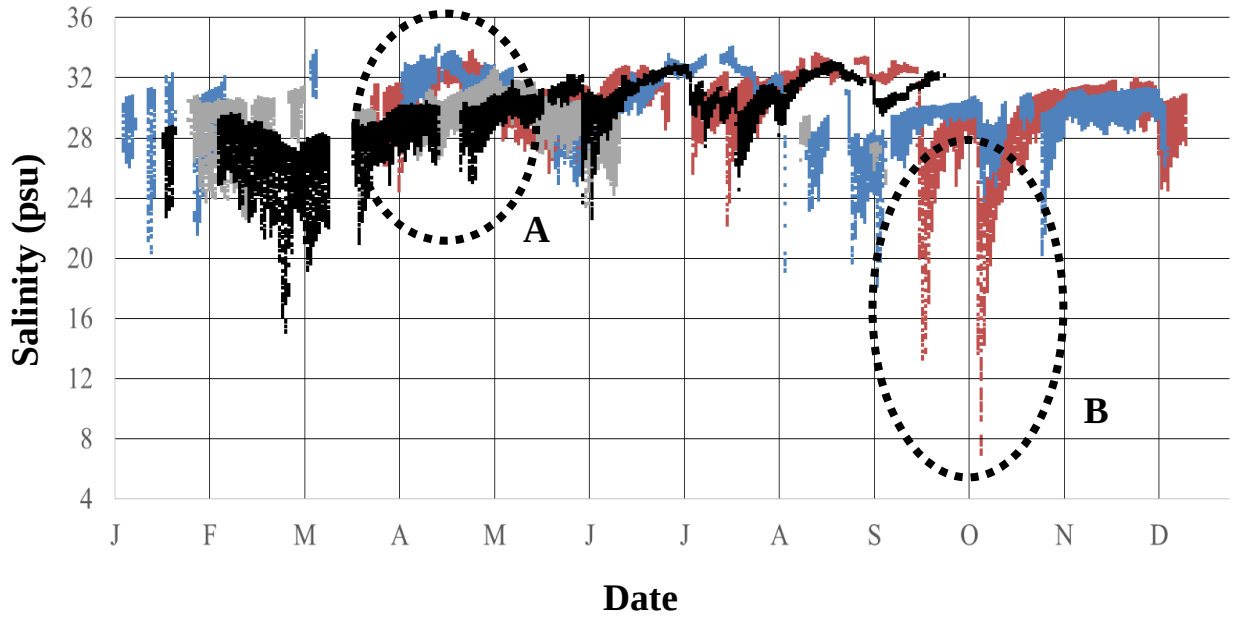


Fig. 2-1-9 Salinity (psu) for the Wachapreague water quality station during 2016 (red), 2017 (blue), 2018 (gray) and 2019 (black). Circled areas labelled "A" and "B" are referenced in the Discussion.

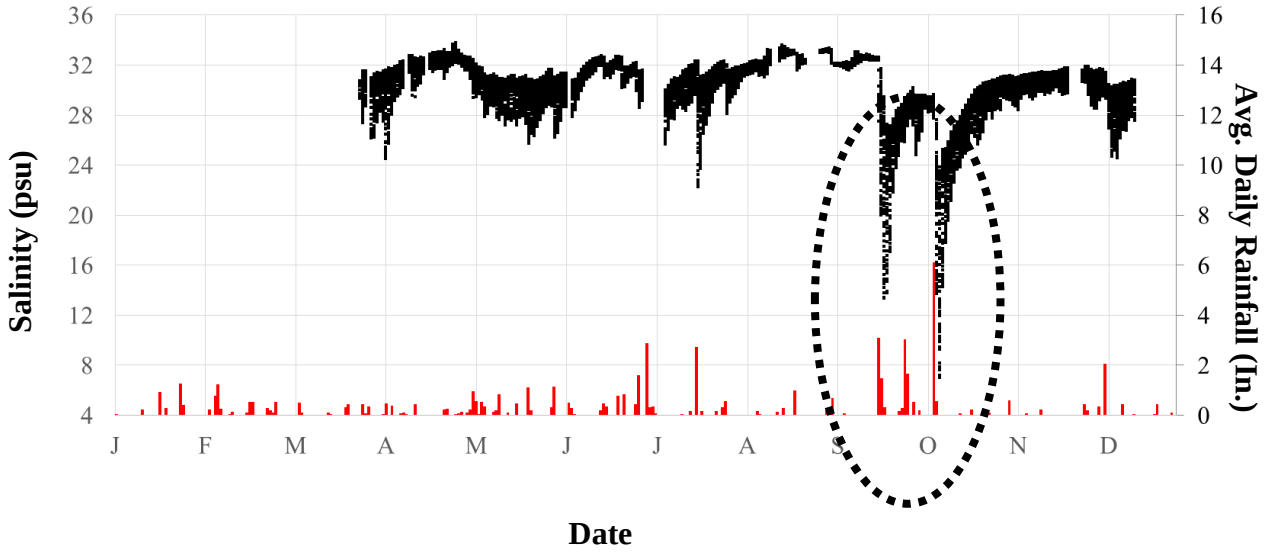


Fig. 2-1-10 Salinity (psu) for the Wachapreague water quality station during 2016 (black) plotted on one axis and average daily rainfall for Accomack County, VA (red bars) on the other axis (CoCoRaHS Network; https://www.cocorahs.org/ViewData/). The circled area, discussed in the Discussion text, exemplifies the relationship between extreme rainfall and salinity events.

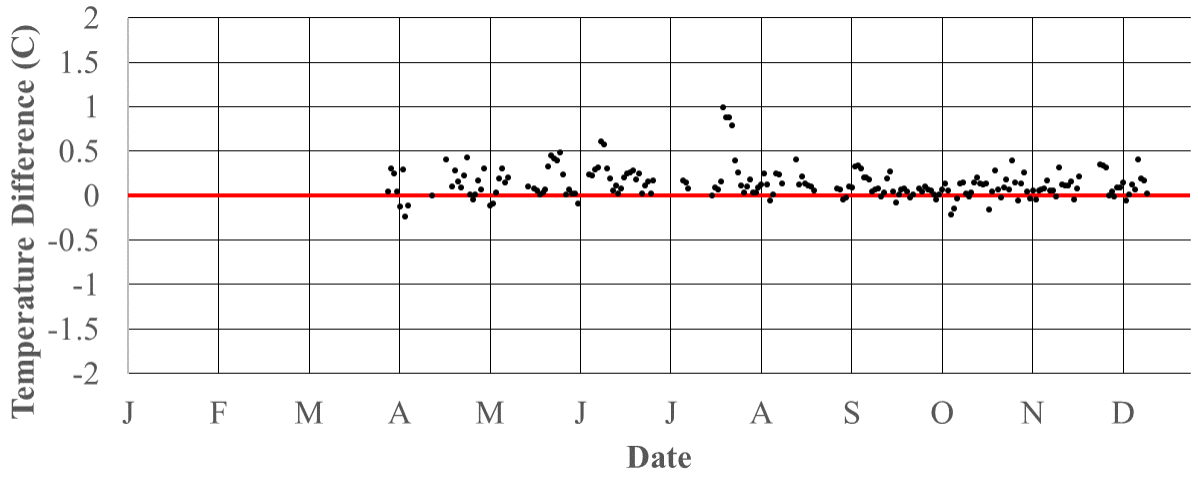


Fig. 2-1-11 Difference in average daily water temperature (°C) between ESL and NOAA water quality stations (WT_{ESL}-WT_{NOAA}) in Wachapreague VA, for days when >85% of expected readings were captured for both stations during 2016 (n=204 days).

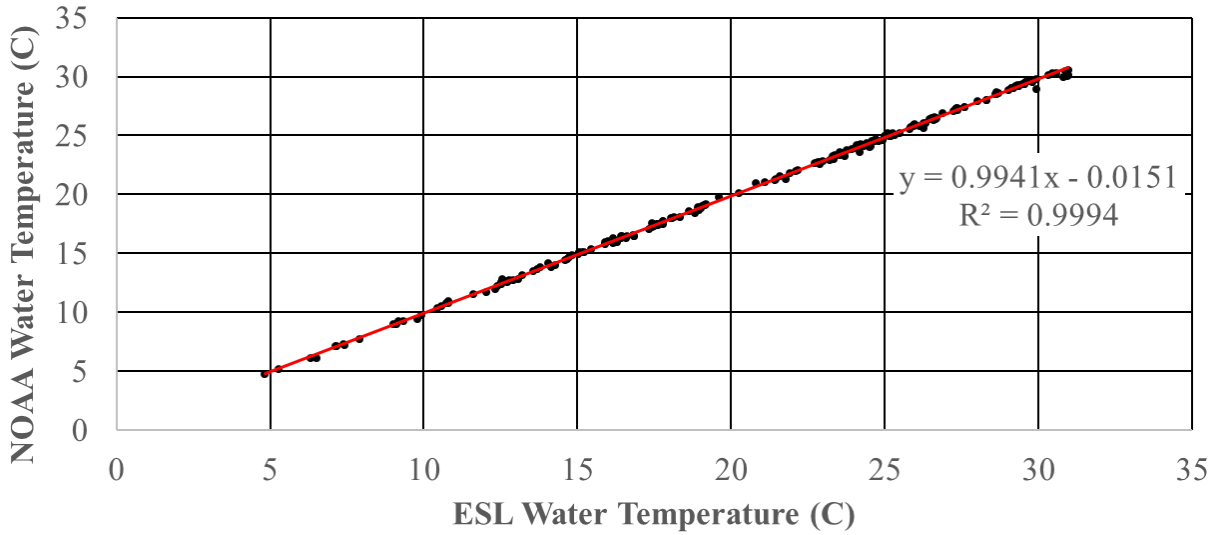


Fig. 2-1-12 Comparison of paired average daily water temperature (°C) from ESL and NOAA water quality stations (WT_{ESL},WT_{NOAA}) in Wachapreague VA, for days when >85% of expected readings were captured for both stations during 2016 (n=204 days ; relationship equation and R^2 values based on simple linear regression).

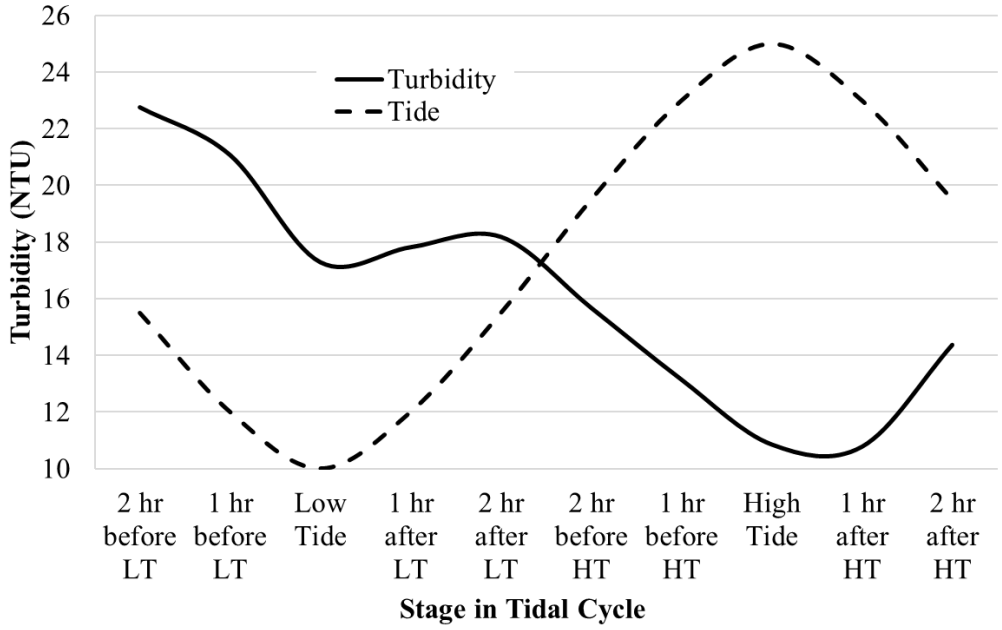


Fig. 2-1-13 Tide and turbidity correlation in the Wachapreague Channel using 2017 turbidity averages at various time points during a tidal cycle. The broken line is an arbitrary, visual representation of the tidal time points displayed on the X axis.

Chapter 2. Water Quality

Section 2-2: Data Flow surface water characterization

Authors: Mark J Brush[a], Richard A Snyder[b], PG Ross[b]

[a]Virginia Institute of Marine Science, Gloucester Point, VA
[b]Virginia Institute of Marine Science, Eastern Shore Laboratory, Wachapreague, VA

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Partial		Planned	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).

Methods

The system we deployed on Carolina Skiffs is shown in Figure 2-2-1. Vessel tracks ran from Nickawampus/Finney Creek (north of the town of Wachapreague) to Wachapreague Inlet via Wachapreague Channel and Bradford Bay/Millstone Creek. These tracks provide an inland to ocean spatial range. Each cruise lasted from 1 to 3 hr.

Eight water quality parameters were measured: water temperature, salinity, specific conductance, pH, dissolved oxygen, turbidity, chlorophyll-a, and blue-green algae (Table 2-1-2). These parameters were measured at 1-minute intervals using a YSI multiparameter 6-port EXO2 Sonde. Dissolved oxygen, turbidity, chlorophyll, and BGA readings were determined using optical sensors (i.e. sensors that use a beam of light to calculate parameter measurements). The

EXO2 Sonde sensors were calibrated prior to use. 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).

2017-2018 Results and Discussion

Data Flow cruises were undertaken during the upper half of a flood tide on 15 May 2017 and during mid-ebb tide on 14 May 2018. Human error resulted in no data collection for 2019. Data from May 2017 and May 2018 are visualized below using ESRI GIS software.

Salinity traces (Figs 2-2-2 and 2-2-5) show very little input of fresh water from the land, with low values in Nickawampus/Finney Creek at around 28 PSU in 2018 and ~26 PSU in 2017, and nearly full strength seawater in Wachapreague Channel and throughout the marsh system. Short drainages dominated by groundwater discharge have minimal impact on the ocean flushing of the system with 1.5 m tidal amplitude. A temperature gradient is also evident with spring warming the land surface and shallow waters resulting in higher temperatures closer to the mainland, and cooler ocean water temperatures closer to the inlet (Fig. 2-2-2). Chlorophyll values indicate higher biomass in the mid region of the system, possibly the result of higher turbidity in Nickawampus/Finney creek (Figs 2-2-6 & 2-2-4) limiting phytoplankton use of nutrients, tidal resuspension of benthic microalagae, and/or residence time of the shallow coastal bays. High turbidity near the inlet, shown in Figure 2-2-4, is likely due to the oceanic spring bloom combined with suspended sediment from offshore wave action on sandbars and the barrier islands the day of the measurements. Very little spatial variation was observed for oxygen concentrations or pH, although pH was slightly lower closer to more acidic freshwater sources than nearer the ocean (Figs 2-2-3 & 2-2-5) as would be expected.

Comparison to Previous Years

As more years of water quality data are acquired, 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 Darian Kelley, Justin Paul, Glenn Brundage, and Edward Smith for sonde preparation, data flow system fabrication and field help.

Table 2-2-1. Description of 8 water quality parameters measured using an EXO2 Sonde integrated in a Data Flow rig.

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).

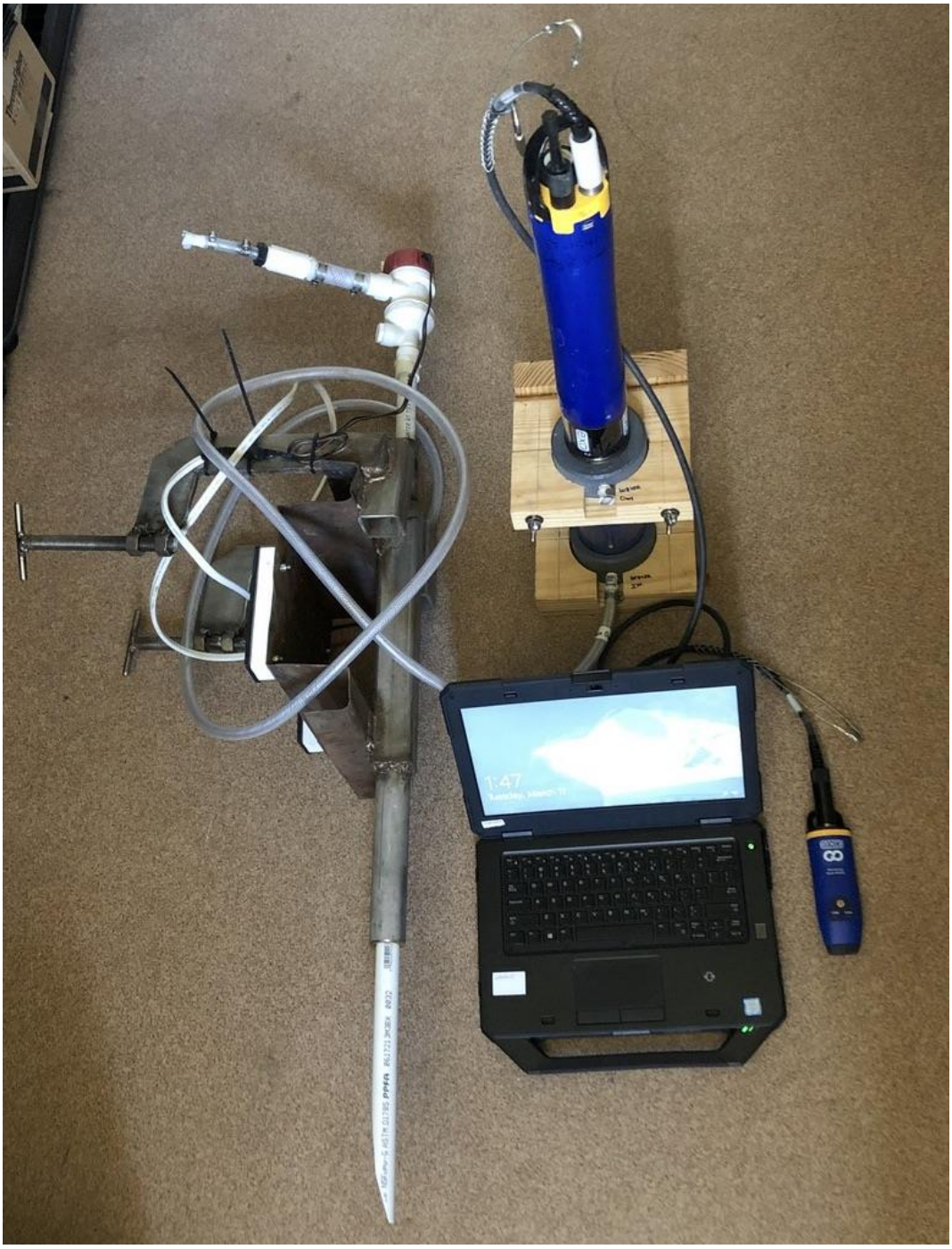


Fig. 2-2-1 Data flow setup. Transom mount hydraulic ram and bilge pump (left) to send water to a YSI Exo2 Datasonde with a flow cell held in a wooden bracket (upper right), cabled to an ExoGo GPS antenna and data integrator (lower right) to send by blue tooth georeferenced sonde data to a laptop.

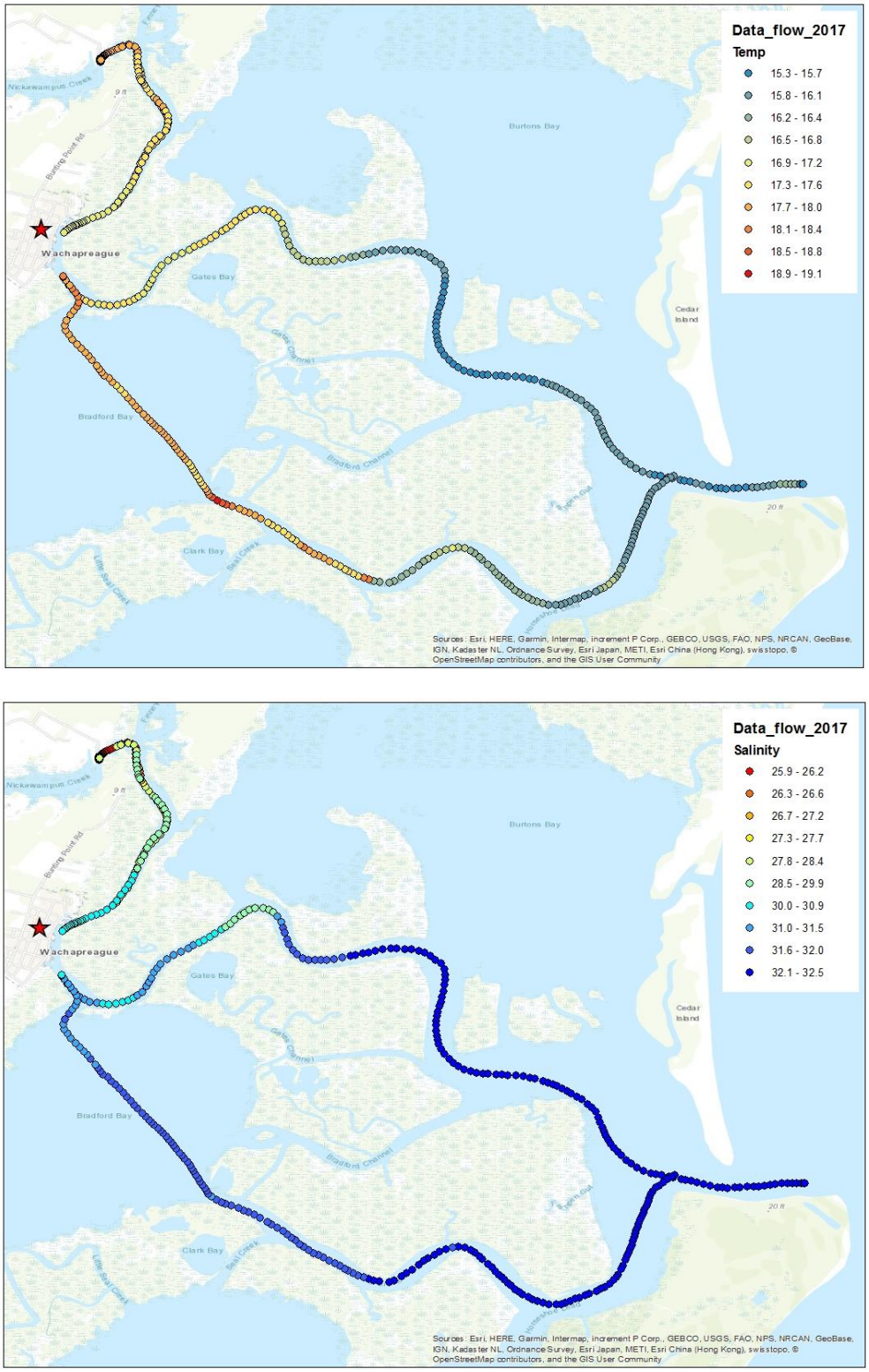


Fig. 2-2-2 GIS plot for water temperature (°C) and salinity (psu) during a 3 hr data flow cruise during the upper half of an incoming tide near Wachapreague, VA on 15 May 2017.

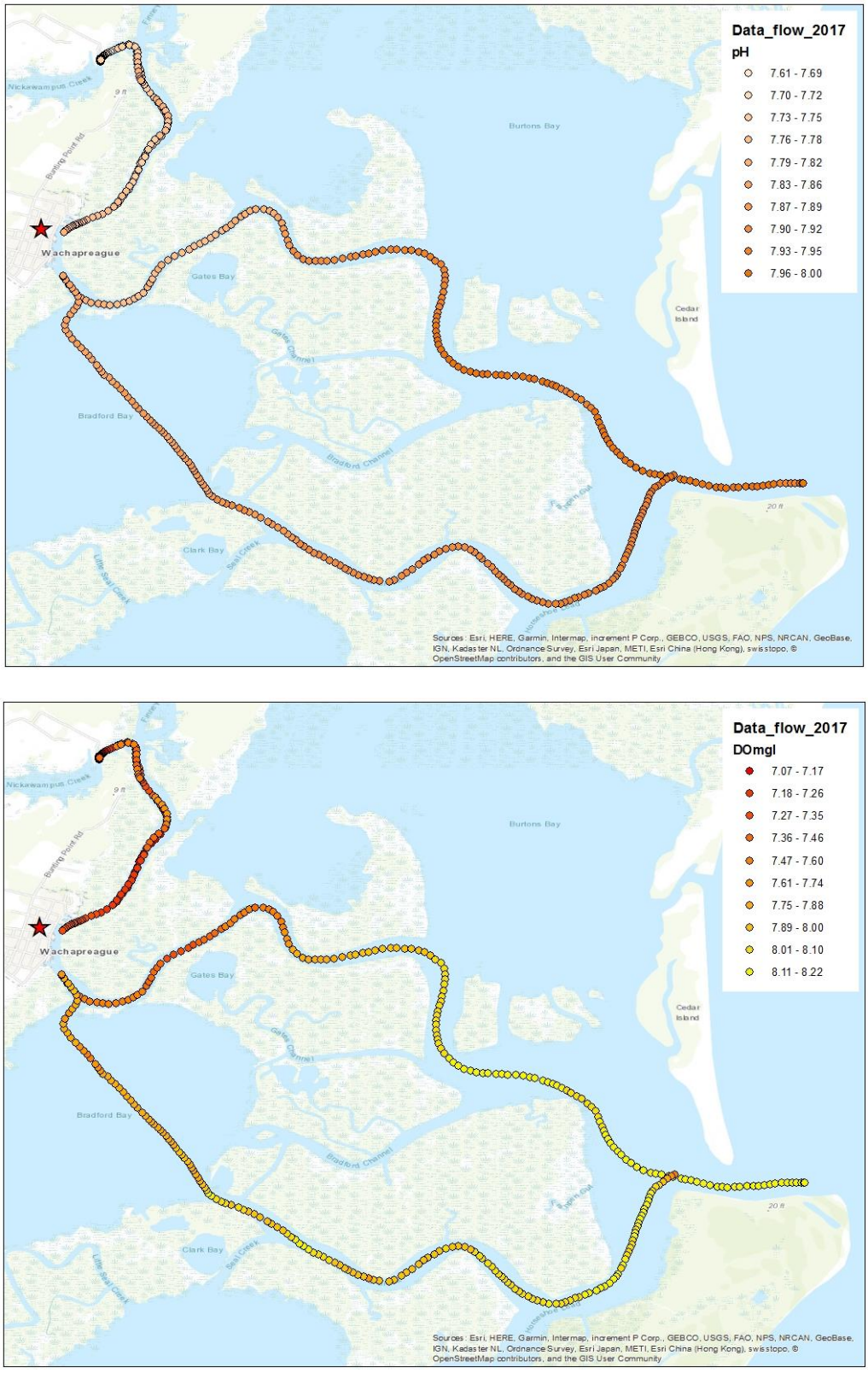


Fig. 2-2-3 GIS plot for pH and dissolved oxygen (mg/L) during a 3 hr data flow cruise during the upper half of an incoming tide near Wachapreague, VA on 15 May 2017.

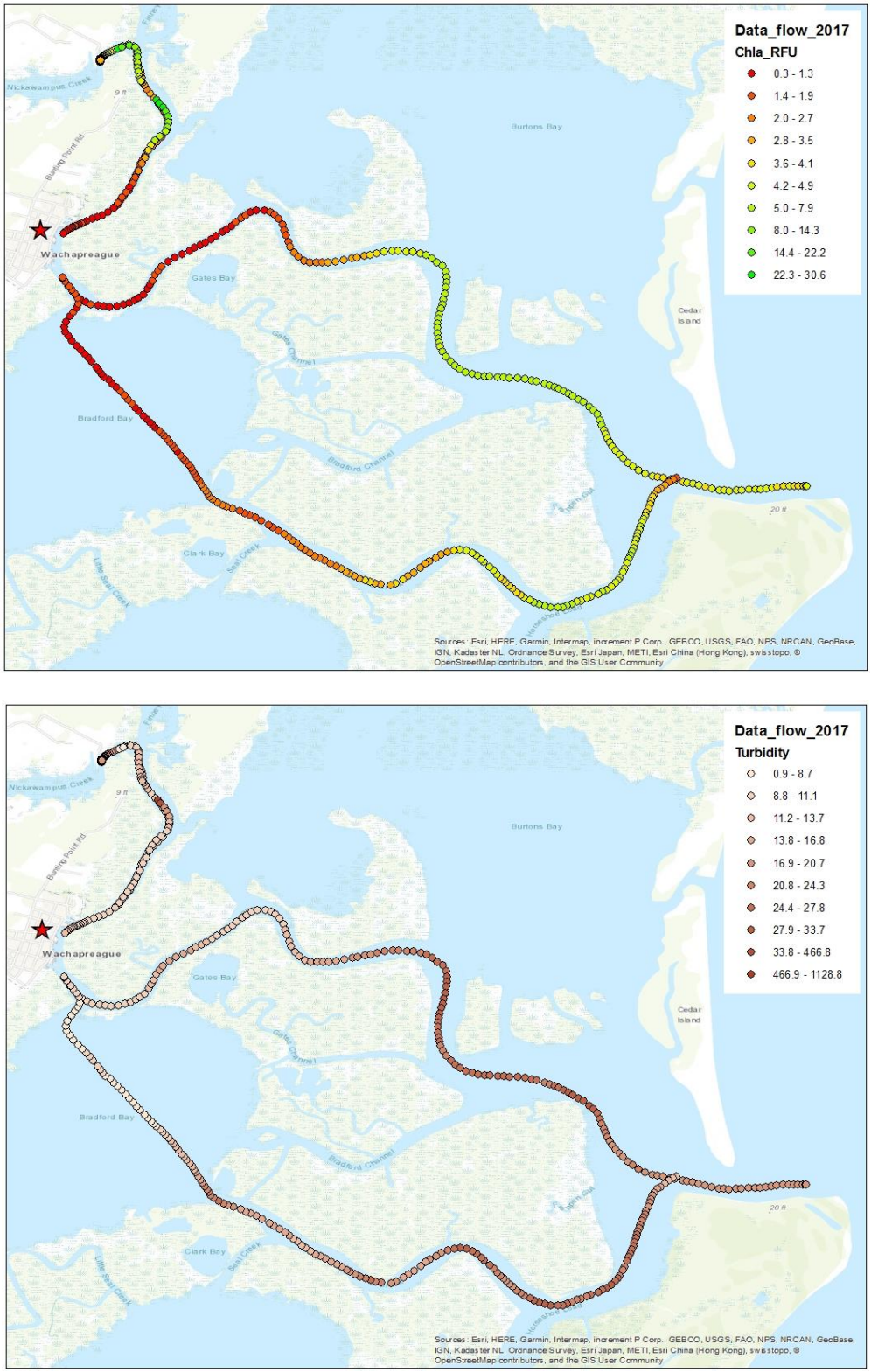


Fig. 2-2-4 GIS plot for Chlorophyll-*a* concentration (RFU) and turbidity (NTU) during a 3 hr data flow cruise during the upper half of an incoming tide near Wachapreague, VA on 15 May 2017.

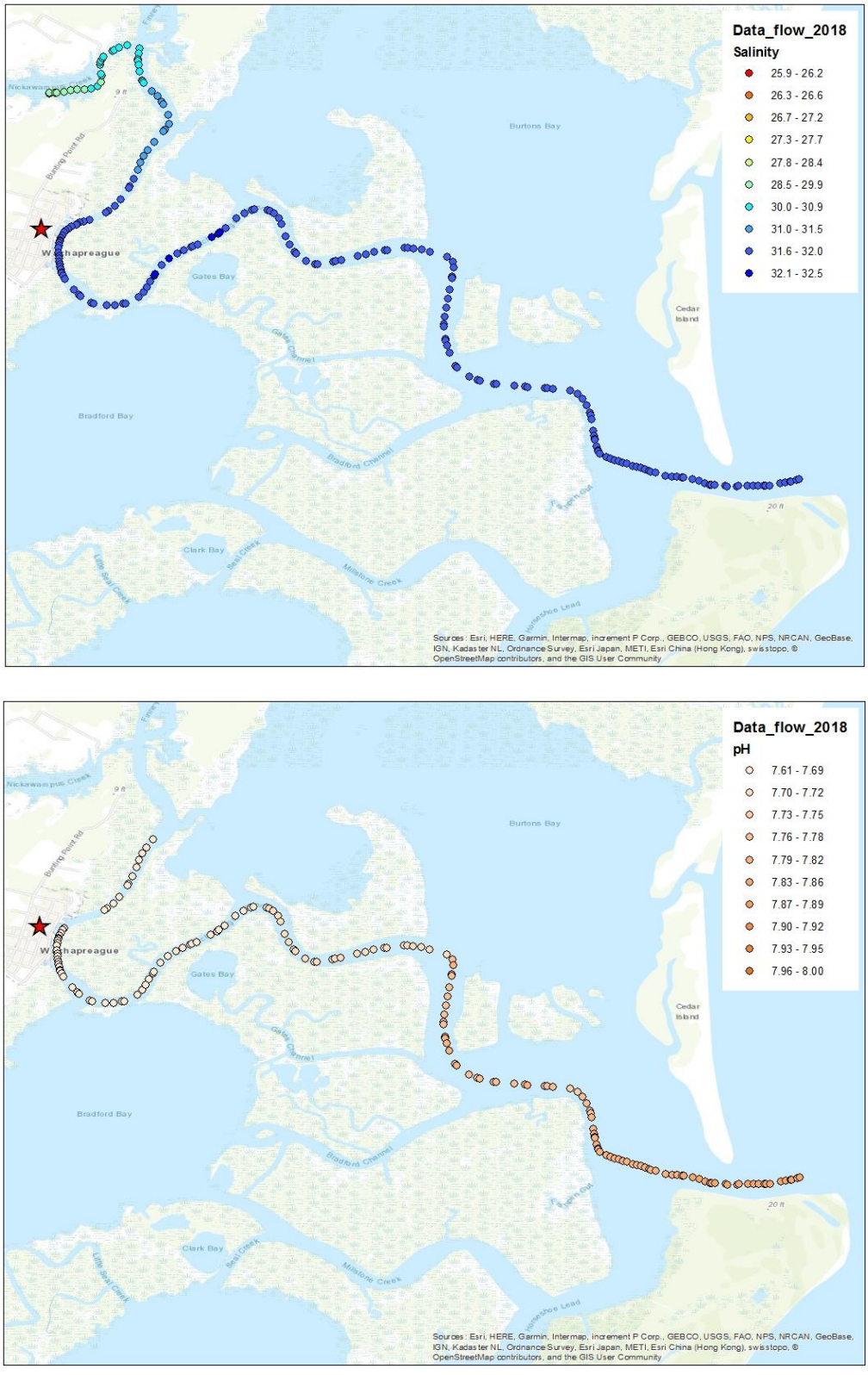


Fig. 2-2-5 GIS plot for salinity (psu) and pH during a 0.75 hr data flow cruise during the mid-ebb tide near Wachapreague, VA on 14 May 2018.

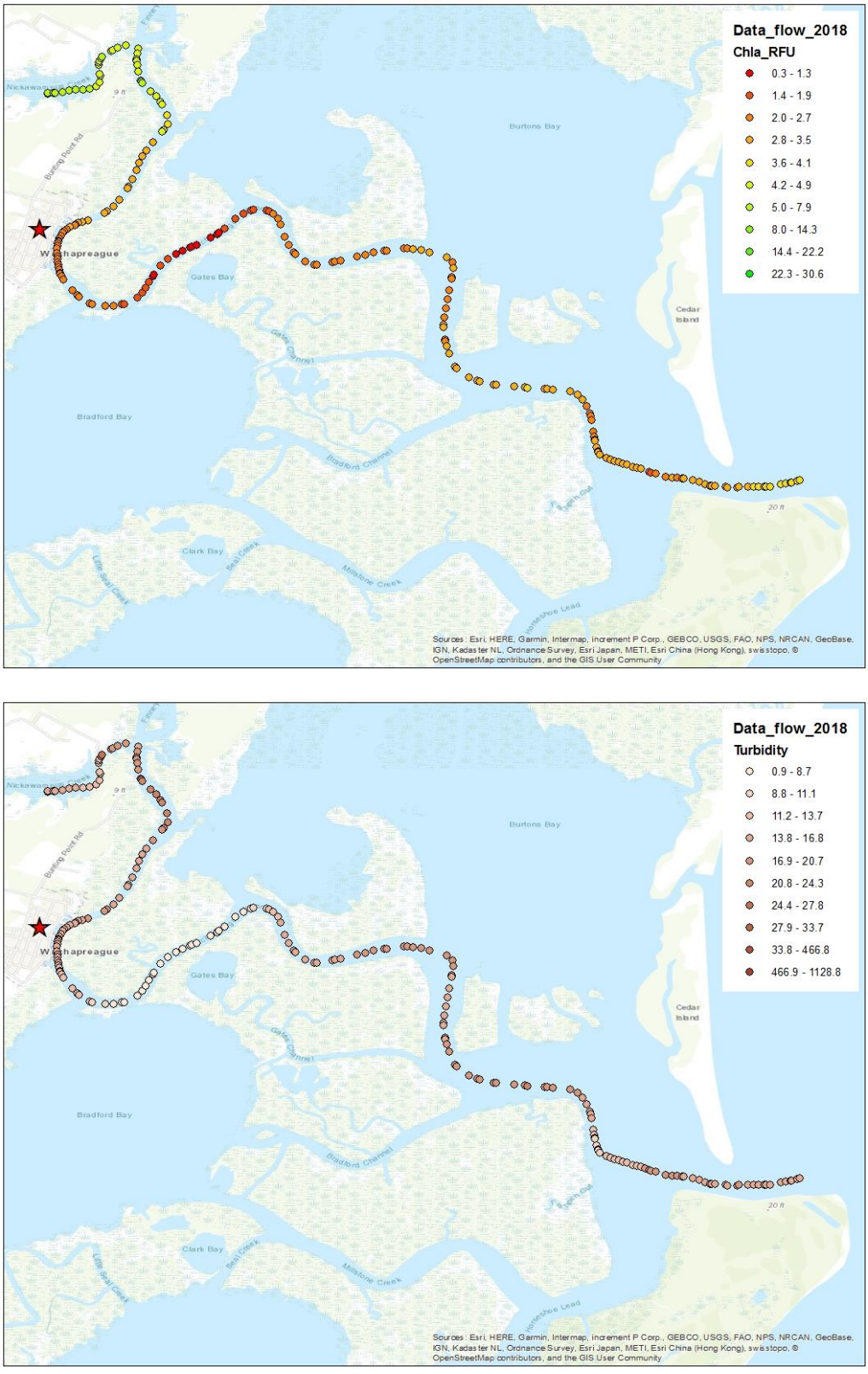


Fig. 2-2-6 GIS plot for Chlorophyll-*a* concentration (RFU) and turbidity (NTU) during a 0.75 hr data flow cruise during the mid-ebb tide near Wachapreague, VA on 14 May 2018.

Chapter 3. Biofilm Community

Authors: Richard A Snyder, PG Ross & Chris Bentley

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Planned	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 (microbiome), 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.

Study Area & Methods

Surface water biofilm arrays were deployed at five stations near Wachapreague (Fig. 3-1-1) from June 5 to August 7, 2018 and June 3 to July 29, 2019. 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
- taxonomic identification (live & fixed)

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 dessicator 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

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. These samples are currently archived at ESL waiting for time/funding to process. A collaborator at the University of Alabama-Birmingham (Krueger-Hadfield) will be processing a set of these samples to augment her study of macroalgal dispersal within the system. ESL samples are planned for analysis of prokaryotic and eukaryotic community structure and diversity.

Taxonomic Identification

One side of a plate was scraped into a container using a sterile squeegee and filtered seawater. This material/liquid was then placed in a 20 ml scintillation vial pre-loaded with 1 ml non-acid Lugol's iodine (2%). These samples are currently archived at ESL for visual observation and taxa identification at a later date. For several samples, another side of a plate was scraped into a container using a sterile squeegee and filtered seawater. This material/liquid was then placed in a 20 ml scintillation vial and refrigerated overnight. Within 24 hours, live observation was made using a compound light microscope and broad taxa identified to help develop a basic community structure and spatial differences in species distributions. To date, this has only been used as a teaching tool for student interns.

2018 & 2019 Results and Discussion

Total Solids & % Organic Matter

Trends for total solids (biofilm dry weight) between stations were consistent for 2018 and 2019, with a general increase during the summer assay period (Table 3-1-1; Fig. 3-1-3; Fig. 3-1-6). Total solids were highest at the Finney Creek site, followed by Burtons Bay, Bradford Bay, Wachapreaue Inlet, and ESL as the lowest (Table 3-1-1; Fig. 3-1-3; Fig. 3-1-6). This spatial trend fits what is usually assumed for a land-to-sea gradient, with the exception of the ESL site. This may be partially explained by the trends for % organic matter within the total solids, with the Finney Creek station showing a higher non-combustible fraction (lower % organic matter) and ESL pier showing the highest % organic matter (Table 3-1-1; Fig. 3-1-4; Fig. 3-1-7). This reflects the inorganic sediment contribution to total mass, and the inland Finney Creek site would be subject to more suspended sediments than others.

Chlorophyll

The Chlorophyll accumulation on 7 day old plates also increased during the summer assay period (Table 3-1-1; Fig. 3-1-5; Fig. 3-1-8) with Finney Creek and Wachapreague Inlet showing the most algal growth response, but likely for different reasons. Finney Creek has a high turbidity, consistent with the high total solids data, but is also closest to the land runoff where most of the nutrients coming into the system are derived. The Wachapreague Inlet site would be more affected by ocean waters that would have lower nutrient concentrations, but also clearer water that would be less restrictive to light availability in the water column and as solids accumulating on plates.

Previous sampling of plates during the 7 day incubation period indicated exponential growth of chlorophyll over time (data not shown). Assuming this exponential growth holds for all stations and dates, the specific rate of increase (μ) 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 3-1-2). 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.

Stable Isotopes & DNA

These samples have been archived during 2018 & 2019 for subsequent elemental analysis. Results will be integrated into future reports and updated on the EMP web page when results are available.

Currently we are looking for funding sources to process DNA samples. Field samples have been preserved and undergone initial lab preparation for subsequent processing to determine diversity, distribution and stability in prokaryote and eukaryote portions of the biofilm community. We have shared DNA samples with a research collaborator from the University of Alabama Birmingham who is interested in dispersal and settlement in macroalgae. This type of interaction is one of the reasons in pursuing the EMP work, that is to provide environmental context and synergistic datasets that would add value to researchers and educator visiting VIMS ESL.

Taxonomic Identification

Diatoms representative of seaside biofilms are shown in Figure 3-1-9. *Cylindrotheca* is a common surface associated form, as are the stalked triangular diatoms of the genus *Licmophora*. Pennate diatoms exist as individual cells gliding over surfaces as well as those building and living within tubes. We are seeking a collaborator for diatom taxonomy to compare with molecular community structure data for future compilations of the data.

Acknowledgements

We would like to thank Jazmine Evans, Kirsten Travis, Evan Lawrence, Mary Holmes and Anna Hartman for field and laboratory assistance and Edward Smith, Justin Paul and Glenn Brundage for gear fabrication.

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Table 3-1-1. Summary of mean biofilm total solids (g m^{-2}), organic matter (%) and chlorophyll-a (µg cm^{-2}) at each of 5 sites near Wachapreague, VA during 2018 & 2019.

Site #	Metric	2018	2019	Average[a] (2014-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
1 ESL	Total Solids (g m^{-2})	10.5	31.6	*n/a*	202.0	*n/a*
	Organic Matter (%)	16.5	17.6	*n/a*	6.7	*n/a*
	Chlorophyll-a (µ cm^{-2})	--	21.3	*n/a*	--	*n/a*
2 Burtons Bay	Total Solids (g m^{-2})	32.0	30.0	*n/a*	-6.4	*n/a*
	Organic Matter (%)	14.8	16.5	*n/a*	11.7	*n/a*
	Chlorophyll-a (µ cm^{-2})	--	22.7	*n/a*	--	*n/a*
3 Finney Creek	Total Solids (g m^{-2})	51.8	56.8	*n/a*	9.6	*n/a*
	Organic Matter (%)	15.3	14.7	*n/a*	-3.8	*n/a*
	Chlorophyll-a (µ cm^{-2})	--	32.8	*n/a*	--	*n/a*
4 Bradford Bay	Total Solids (g m^{-2})	27.5	26.7	*n/a*	-2.6	*n/a*
	Organic Matter (%)	14.7	16.9	*n/a*	14.8	*n/a*
	Chlorophyll-a (µ cm^{-2})	--	26.8	*n/a*	--	*n/a*
5 Wach. Inlet	Total Solids (g m^{-2})	11.5	21.3	*n/a*	86.2	*n/a*
	Organic Matter (%)	14.3	15.6	*n/a*	9.3	*n/a*
	Chlorophyll-a (µ cm^{-2})	--	30.9	*n/a*	--	*n/a*

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

Table 3-1-2. 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.

	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

Fig. 3-1 Locations of 5 oyster settlement monitoring sites near Wachapreague, VA for 2018 (red polygons denote the ESL-EMP study areas).

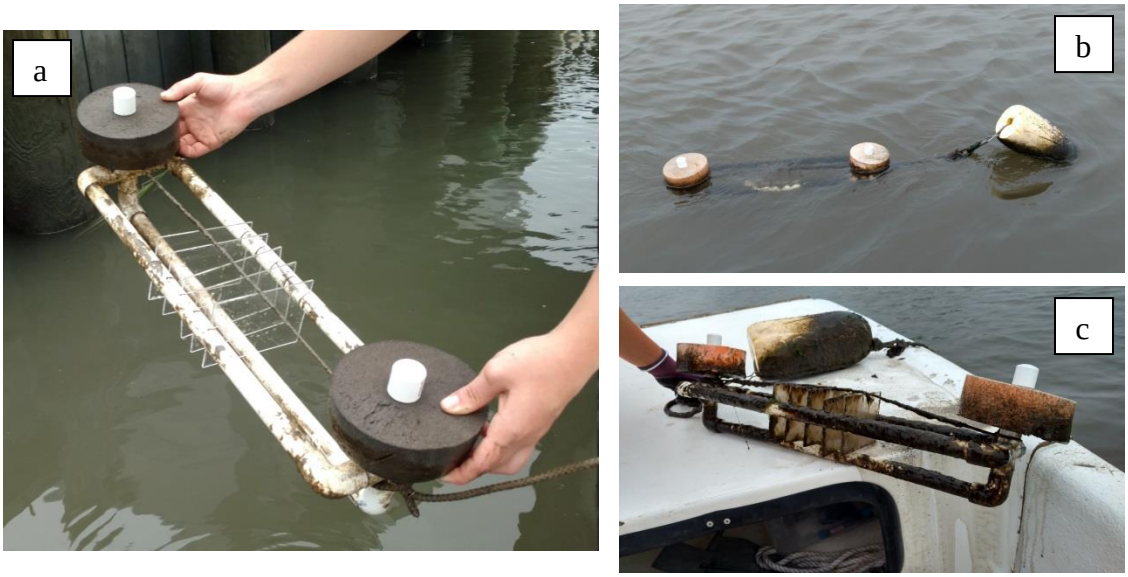

Fig. 3-2 Biofilm array a) before, b) during and c) after deployment.

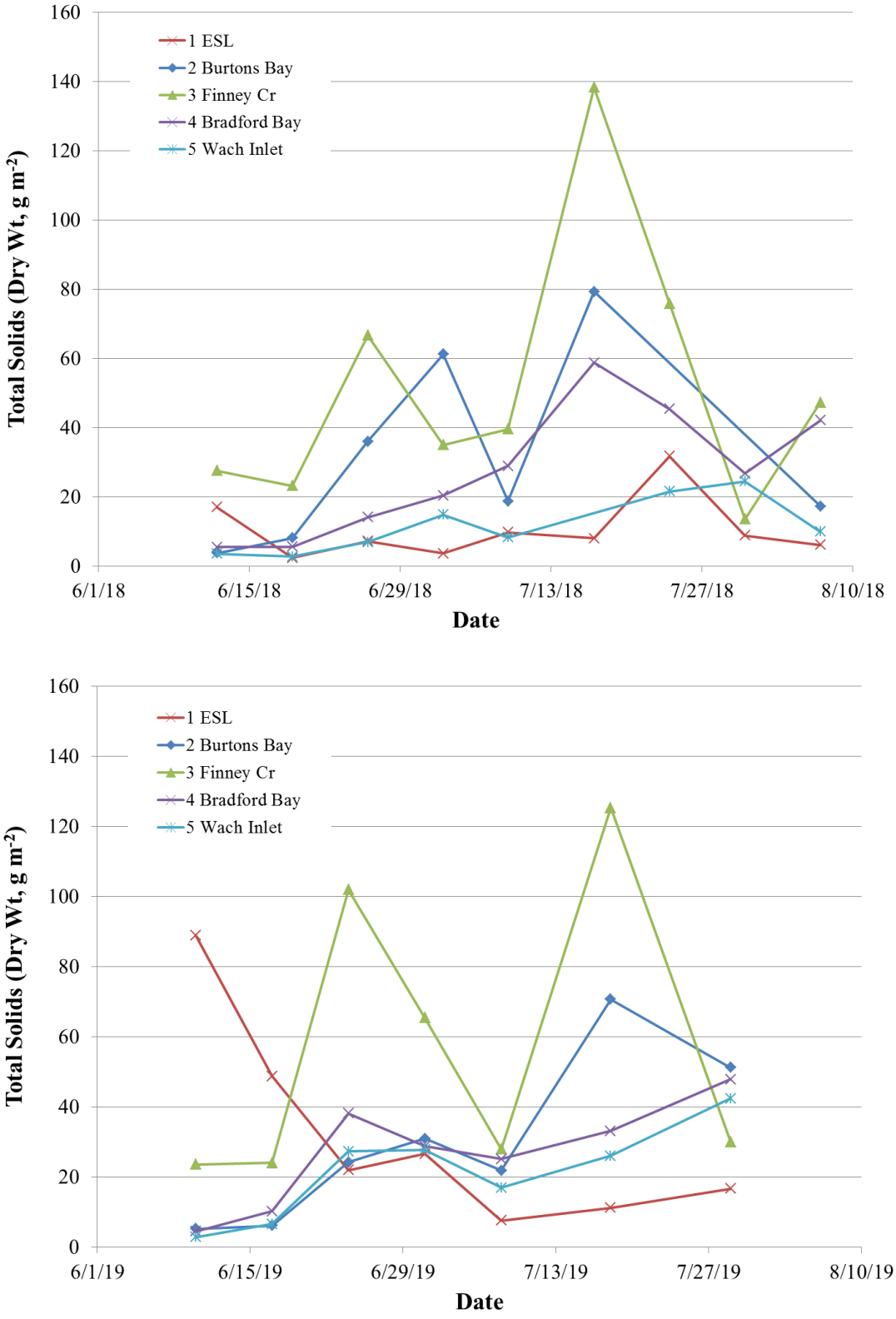

Fig. 3-3 Biofilm total solids (dry wt., g m^{-2}) for the 5 study sites during June-early August 2018 and 2019.

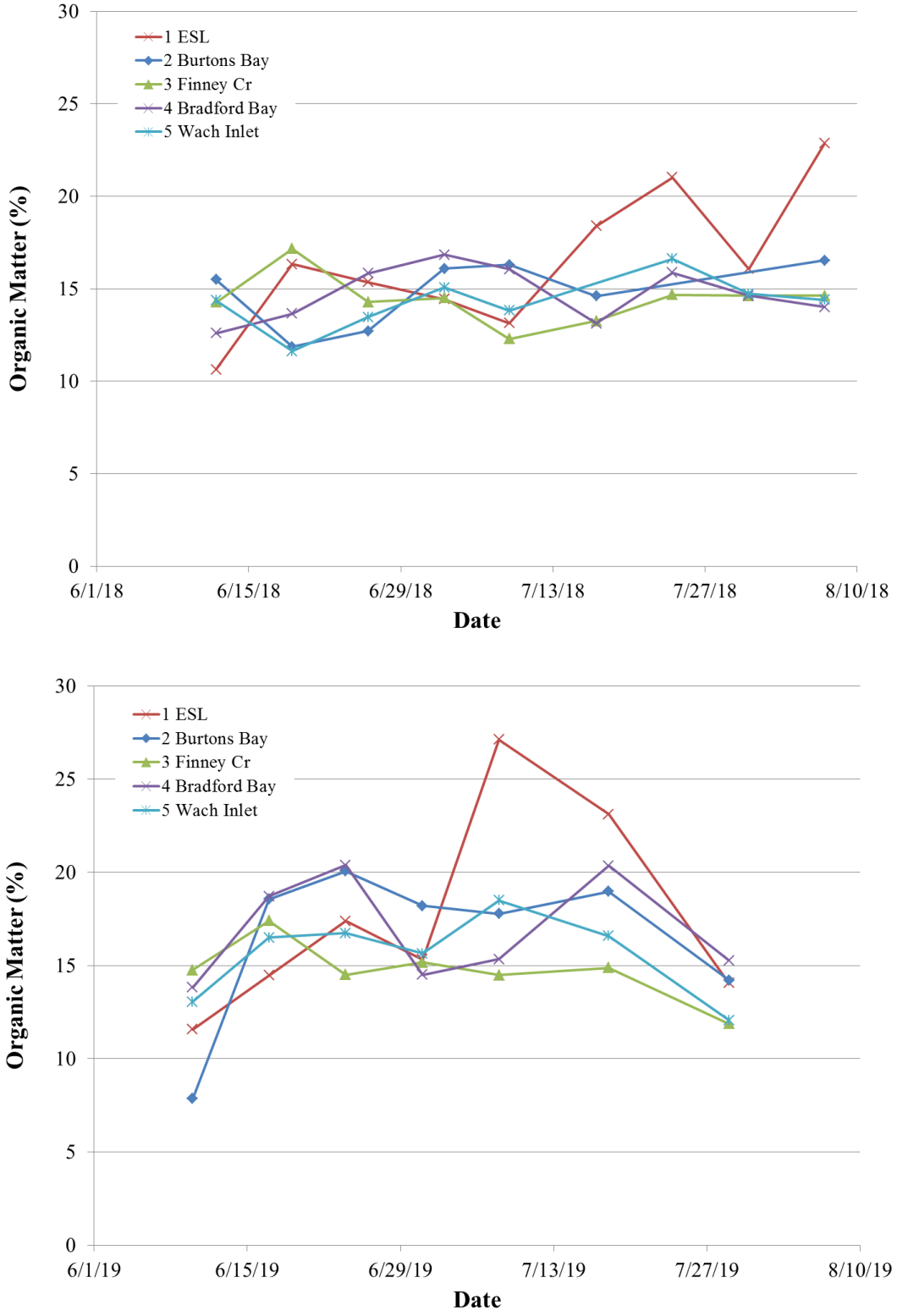

Fig. 3-4 Biofilm organic matter (%) for the 5 study sites during June-early August 2018 and 2019.

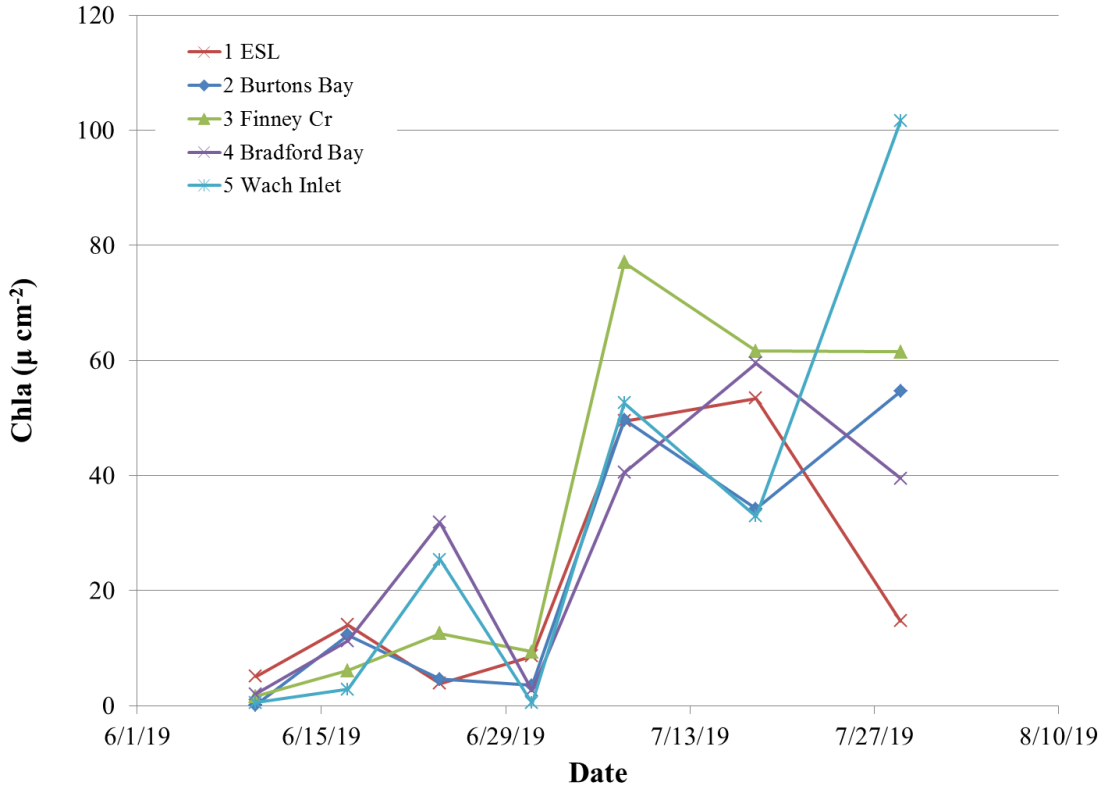

Fig. 3-5 Biofilm chlorophyll-a estimates (µg/cm^2) for the 5 study sites during June-early August 2019.

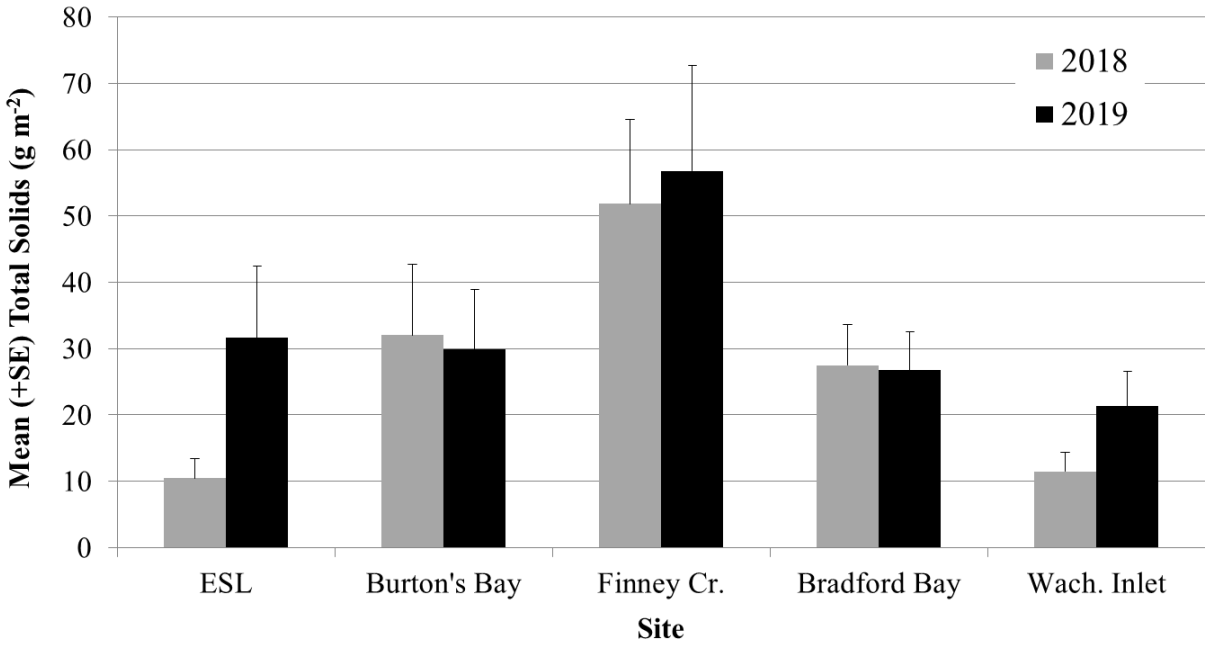

Fig. 3-6 Biofilm mean (+SE) total solids (dry wt., g m^{-2}) for the 5 study sites during 2018 and 2019.

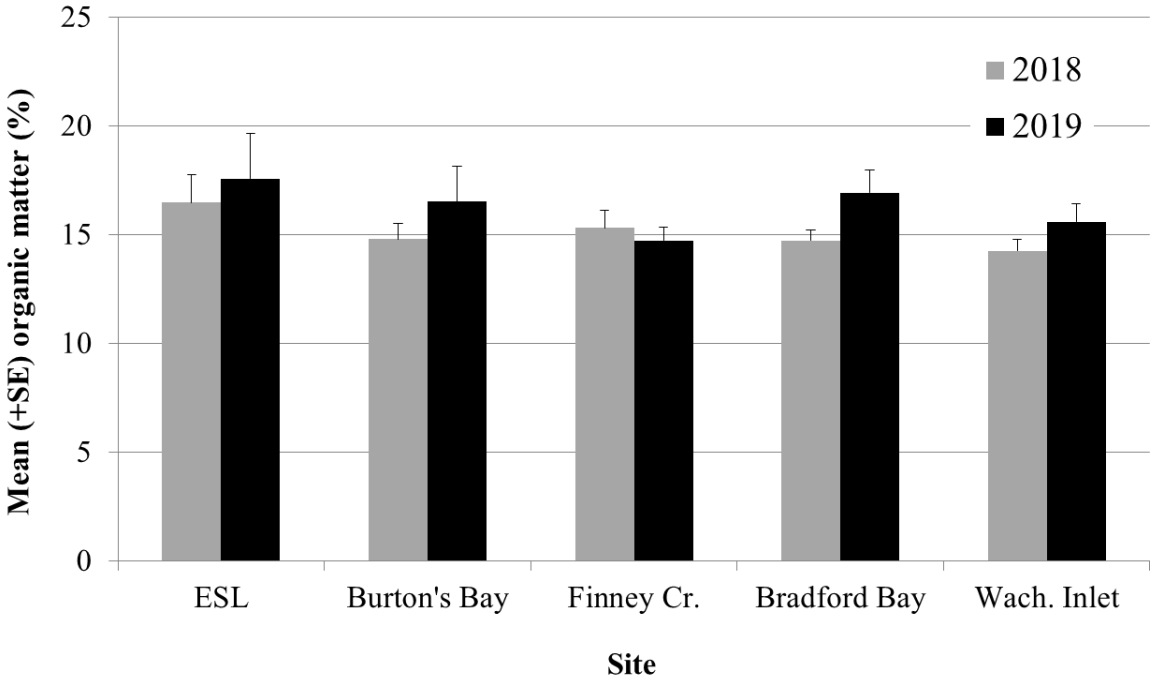

Fig. 3-7. Biofilm mean (+SE) organic matter (%) for the 5 study sites during 2018 and 2019.

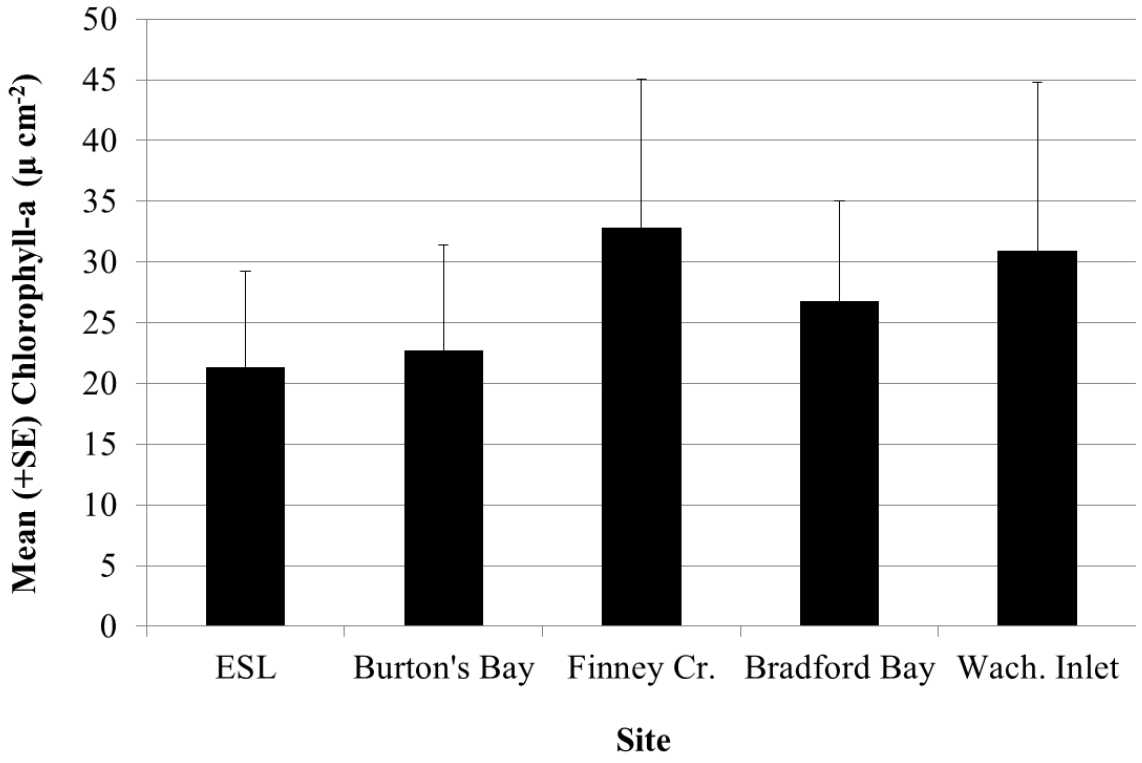

Fig. 3-8 Biofilm mean (+SE) chlorophyll-a (µg cm^{-2}) for the 5 study sites during 2019 only.

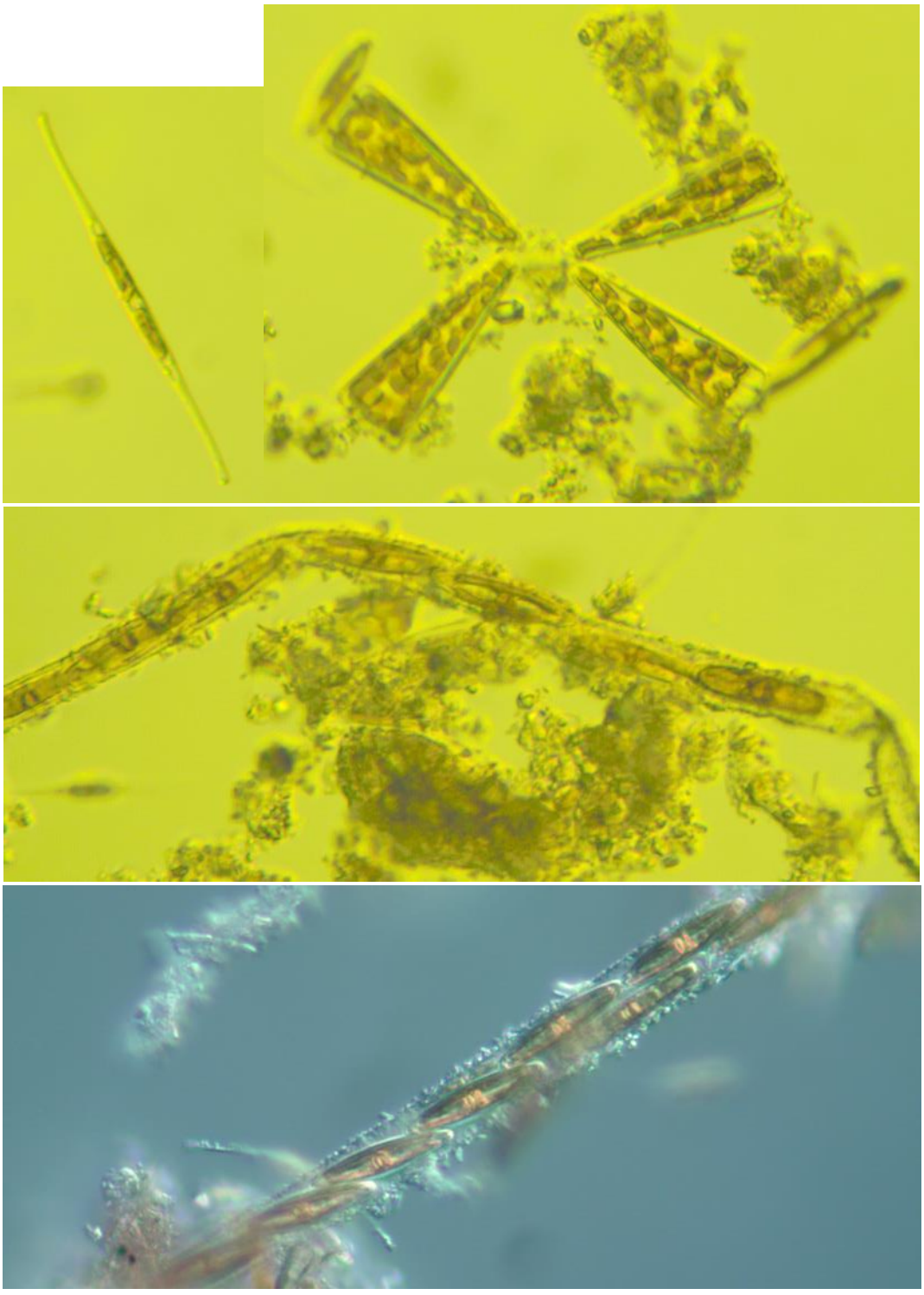

Fig. 3-9 Diatoms representative of seaside biofilms. *Cylindrotheca* (upper left) is a common surface associated form, as are the stalked triangular diatoms genus *Licmophora* (upper right). Pennate diatoms building and living within tubes were also common on the plates (middle and bottom).

Chapter 4. Oyster Population

Section 4-1: Oyster Settlement

Authors: PG Ross & Edward Smith

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Planned	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; a feature that 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 float 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 2 to November 12, 2018 and May 2 to November 21, 2019. 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 2014-2019 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 4 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.

2018 Results

Cumulative annual oyster settlement for the 2018 season showed significant spatial variation between the 5 sites, ranging from 1,029 to 24,795 oysters m^{-2} (Table 4-1-1 and Fig. 4-1-3). The settlement season lasted 132 days between 12-Jun and 22-Oct (Table 4-1-2). Weekly settlement rates also varied spatially and were highest at sites #1 and #5 (ESL and Inlet, respectively), with the coastal bay stations in Bradford (#4) and Burton's (#2) bays showing intermediate settlement and the most upstream site in Finney Creek (#3) having minimal 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 September. Peak weekly settlement rates approached 7,000 oysters m^{-2} at three of the five sites.

2019 Results

Cumulative oyster settlement for the 2019 season showed significant spatial variation between the 5 sites ranging from 833 to 62,471 oysters m^{-2} (Table 4-1-1 and Fig. 4-1-5). The settlement season lasted 154 days between 20-May and 21-Oct (Table 4-1-2). Weekly settlement rates also varied spatially and were highest at sites #1 and #5 (ESL and Inlet, respectively), with the coastal bay stations in Bradford (#4) and Burton's (#2) bays showing intermediate settlement and the most upstream site in Finney Creek (#3) having minimal settlement (Fig. 4-1-4). Generally, there was a large peak during June and July with a slight fall increase for a couple of locations in late September. Peak weekly settlement rates were over 10,000 oysters m^{-2} at two of the five sites.

Comparison to Previous Years

Both 2018 and 2019 seemed to be moderate to average cumulative settlement years, although very high rates were observed at the Inlet site (#5; Table 4-1-1). Differences between 2018 and 2019 varied spatially, with 2019 having less settlement at 4 of the 5 sites, but a large increase at the Inlet site (Table 4-1-1). Similar patterns were observed when 2019 was compared to the average for 2014-2019 (Table 4-1-1). The ESL site (#1) and Inlet site (#5) were consistently the highest cumulative settlement sites in 2014, 2016, 2018 and 2019 (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 2019 compared to 2018 and the 2014-2019 average (Table 4-1-2). This longer period was mainly influenced by an earlier onset of settlement in 2019 while cessation of settlement

remained consistent for the four years reported here (Table 4-1-2). The seasonal period of oyster settlement varied spatially within and across years for both 2018 and 2019, with a larger period observed for 2019 for 4 of the 5 sites compared to 2018 and all 5 of the sites compared to the 2014-2019 average (Table 4-1-2).

Intra-annual timing and weekly settlement rates show similar patterns in 2014, 2018 and 2019, including a general trend of early summer peaks with second slight settlement events during late September to early October (Fig. 4-1-6). Additionally, 2019 exhibited a slight shift to earlier settlement. 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).

Discussion

Based on data for oyster settlement from 2018 and 2019, it is clear that many larvae were present in the coastal lagoon 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 were 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 Wachapregue 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. Monitoring these oyster populations (Chapter 4-2) will be important, if this is the case.

Of course, other factors impact the oyster population. Environmental 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 indicators of factors affecting the oyster population.

As more years of standardized data are collected for oyster settlement, we anticipate being better able to categorize high vs. average vs. poor years and help better compare spatial patterns. Given the potential for coastal change, establishing the current status of the potential in the oyster population and any trends will be an important sentinel for hard substrate habitats and their associated communities (see Chapter 5-2).

2018 & 2019 Acknowledgements

We would like to thank Hunter Leonard, Jazmine Evans, Evan Lawrence, Mary Holmes, Kirsten Travis, Sean Fate and Conor Friedrich-Lovette for field and lab processing 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 2014-2019. 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	Average (2014-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
1-ESL	46,462	5,558	24,795	23,392	25,052	-5.7	-6.6
2-Burton's Bay	23,977	424	7,801	5,044	9,311	-35.3	-45.8
3-Finney Creek	1,579	509	1,029	833	988	-19.0	-15.6
4-Bradford Bay	775	734	5,994	2,442	2,486	-59.3	-1.8
5-Wach. Inlet	--	5,117	19,933	62,471	29,174	213.4	114.1
Average for All Sites Combined	*18,198*	*2,468*	*11,910*	*18,836*	*13,402*	*58.1*	*40.5*

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/m2)

Table 4-1-2. Summary of oyster settlement timing (date) and maximum duration (# days) at each of 5 sites near Wachapreague, VA from 2014-2019. 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	Average (2014-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
1 ESL	# days	96	125	132	154	127	16.7	21.5
	Begin date	26-Jun	21-Jun	12-Jun	20-May			
	End date	30-Sep	24-Oct	22-Oct	21-Oct			
2 Burtons Bay	# days	91	111	111	126	110	13.5	14.8
	Begin date	20-Jun	5-Jul	3-Jul	3-Jun			
	End date	19-Sep	24-Oct	22-Oct	7-Oct			
3 Finney Creek	# days	118	125	132	126	125	-4.5	0.6
	Begin date	26-Jun	21-Jun	12-Jun	3-Jun			
	End date	22-Oct	24-Oct	22-Oct	7-Oct			
4 Bradford Bay	# days	62	111	106	126	101	18.9	24.4
	Begin date	26-Jun	5-Jul	26-Jun	20-May			
	End date	27-Aug	24-Oct	10-Oct	23-Sep			
5 Wach. Inlet	# days	--	125	111	126	121	13.5	4.4
	Begin date	--	21-Jun	3-Jul	3-Jun			
	End date	--	24-Oct	22-Oct	7-Oct			
All Sites Combined	*Max # days*	*118*	*125*	*132*	*154*	*132*	*16.7*	*16.4*
	Begin date	*20-Jun*	*21-Jun*	*12-Jun*	*20-May*			
	End date	*22-Oct*	*24-Oct*	*22-Oct*	*21-Oct*			

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

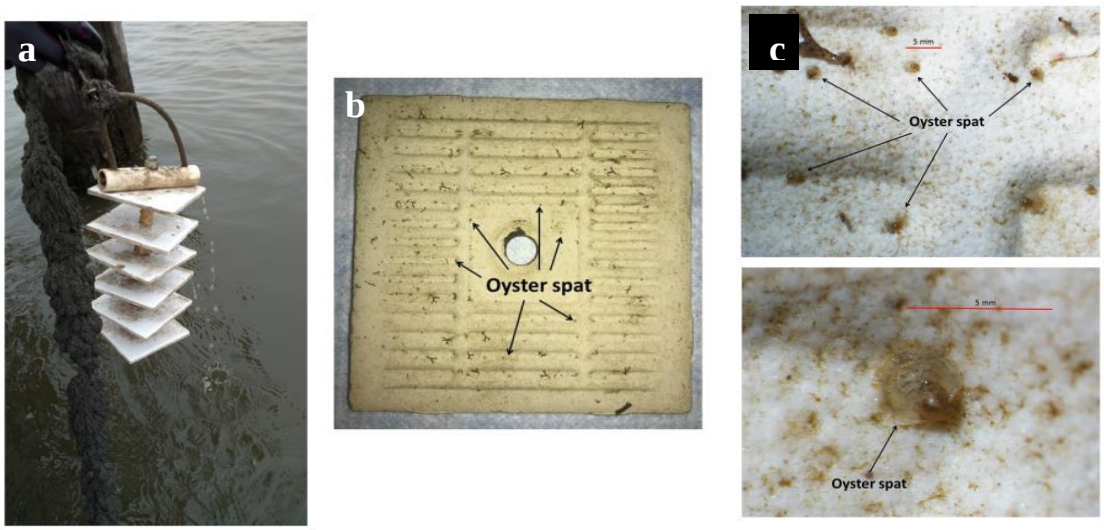

Fig. 4-1-2 Settlement monitoring: a) array being retrieved in field b) tile with oyster spat and c) images of oyster spat on unglazed side of settlement tiles under 2 magnifications.

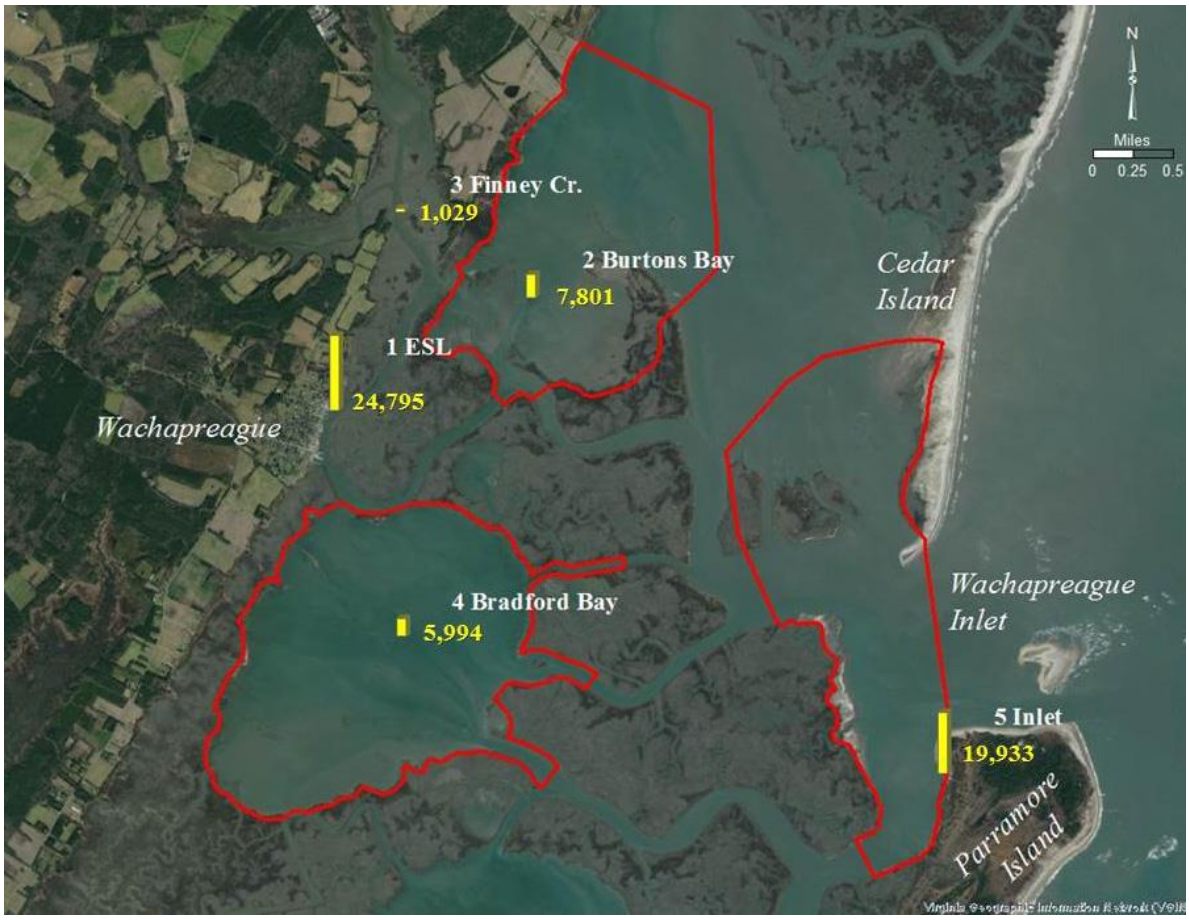

Fig. 4-1-3 Spatial pattern of 2018 cumulative oyster settlement (# oysters m^{-2}) at 5 monitoring sites near Wachapreague, VA.

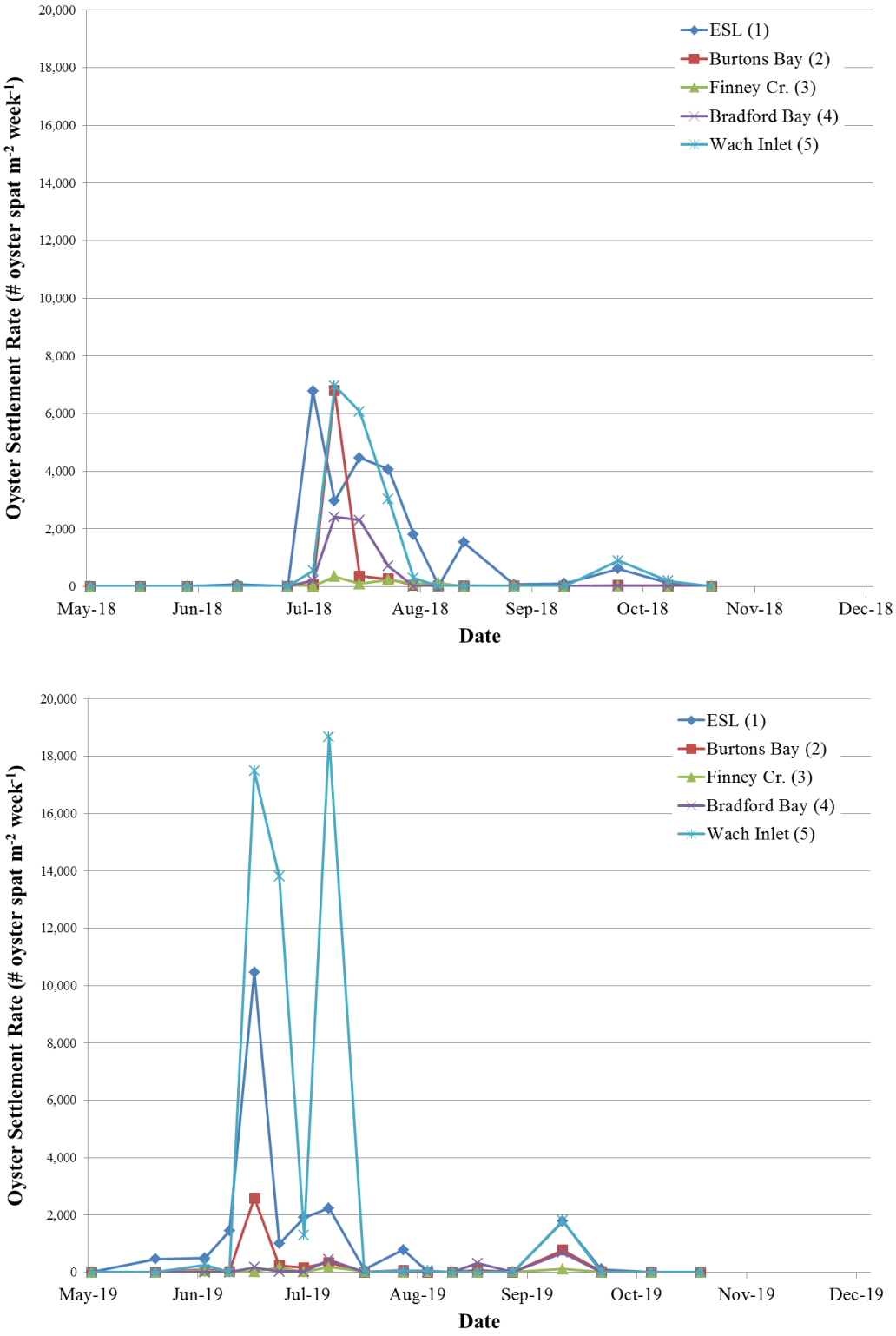

Fig. 4-1-4 Weekly oyster settlement rate (# spat m^{-2} $week^{-1}$) at 5 monitoring stations near Wachapreague, VA during 2018 & 2019.

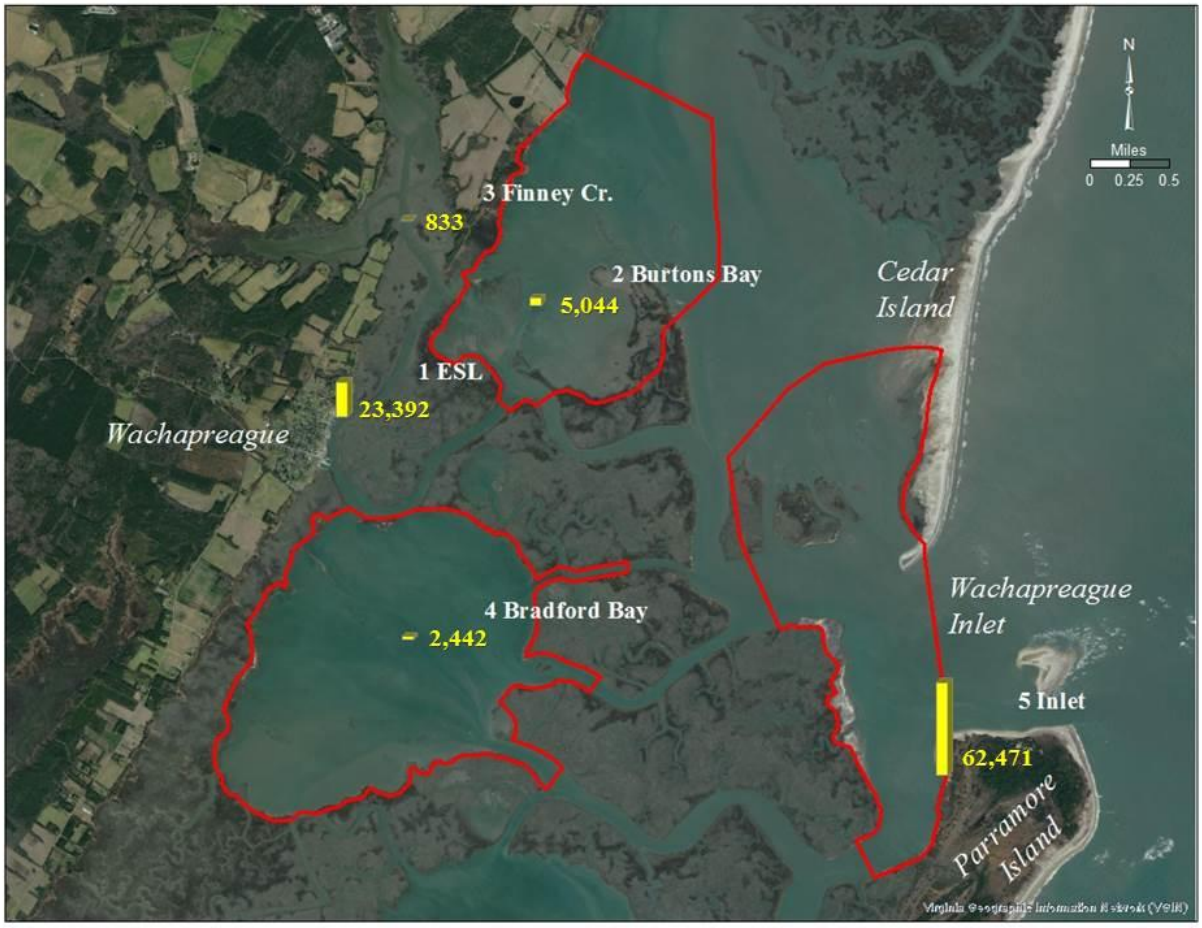

Fig. 4-1-5 Spatial pattern of 2019 cumulative oyster settlement (# oysters m^{-2}) at 5 monitoring sites near Wachapreague, VA.

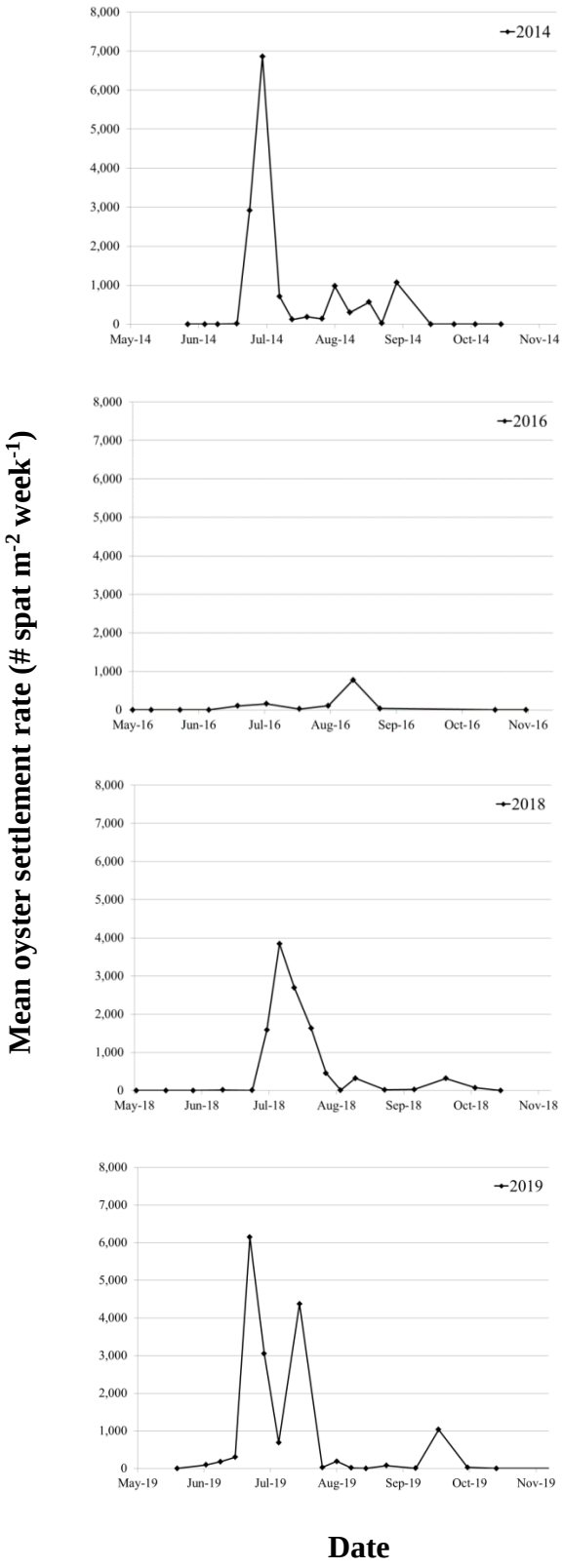

Fig. 4-1-6 Mean oyster settlement rate (# spat m^{-2} $week^{-1}$) at 5 monitoring stations near Wachapreague, VA by date during 2014, 2016 and 2018-2019.

Chapter 4. Oyster Population

Section 4-2: Intertidal Oyster Reef Demographics

Authors: PG Ross

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Planned	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 and one intertidal fringe reef within each of the three EMP geographical areas to monitor (9 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 quadrate 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 July/August 2018. Sampling of these sites was accomplished earlier in 2019 (May/June) to adjust for logistics of sampling and processing.

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 quadrate. 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.

2018 & 2019 Results

The overall oyster density (# m^{-2}) on individual reefs ranged from 160 to 2,592 in 2018 and 104 to 2,096 in 2019 (Tables 4-2-1 & 4-2-2). Individual reef densities were quite variable and there were often substantial differences between crest and flank samples within reefs (see Appendix 4-2-1). Additionally, patch reefs tended to have more oysters than fringe 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 (g m^{-2}) of the oyster population $\geq$ 35 mm on individual reefs ranged from 0 to 357 in 2018 and 1 to 305 in 2019 (Tables 4-2-1 & 4-2-2) and similar differences, as noted above, were seen within reefs. However, differences in biomass between patch and fringe reefs were striking (Tables 4-2-1 & 4-2-2) and were a result of the larger sized of oysters inhabiting the patch reefs relative to the fringing reefs. It is suspected that the difference is related to age of the oysters between these reef structures rather than differences in growth rates. It is possible that these fringing reefs dominated by young oysters represent expanding oyster reefs in the system. For patch reefs, some geographic differences were observed between the three regions, however, differences between 2018 and 2019 were negligible (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. However, due to differences in patch vs. fringe reefs, it is important to analyze each separately. Pooled size distribution data show a definite difference between the two types of reefs; patch reefs show a multi-modal distribution of age classes (Fig. 4-2-3) while fringe reefs contain only small, young oysters (Fig.4-2-4). This difference is the reason density biomass is very low on fringe reefs as noted above. This overall pattern continues when the data from individual reefs are examined (e.g. Fig. 4-2-5). Although quite variable between patch reefs, generally there are multiple age classes present in the 2018 & 2019 sampling (Appendices 4-2-2 to 4-2-4). The three fringe reefs have mainly new recruits (<35 mm), although they may have quite a few of those (Appendix 4-2-5).

In addition to size frequency distributions, to further characterize oyster size on patch reefs only (fringe reefs had few oysters > "spat" category), we report quantities of oysters in three 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, # m^{-2} and % of oysters on individual reefs showed a similar pattern: Spat>Small>Market for both 2018 and 2019 (Tables 4-2-3 & 4-2-4). Inter-annual changes were variable by reef for individual size categories. 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 4-2-5).

Comparison to Previous Years

The first two formal years for the EMP were 2018 and 2019. We do not have any previous data for these specific sites. However, we have similar data from other reefs in the vicinity that were sampled from winter to spring of 2007/2008 (see Ross & Luckenbach 2009 for methods and results). Live oyster density on patch reefs in all Virginia Eastern Shore coastal bays ranged from 477-1,364 m^{-2} in that study with an average of 639 m^{-2} in the region that encompasses the EMP study area. For comparison, we found higher values with an average 1,472 and 1,505 m^{-2} on similar reefs during the 2018 and 2019 EMP, respectively.

Live oyster biomass density on patch reefs ranged from 34-97 g m^{-2} in the previous study with 45 g m^{-2} in the region that encompasses the EMP study area. For comparison, we found 190 and 204 g m^{-2} on similar reefs during the 2018 and 2019 EMP, respectively. It is important to note that the 2007/2008 sampling effort was substantially higher than the 2018 EMP; 60 reefs (348 quadrates) vs. 6 reefs (12 quadrates), respectively. Additionally, patches sampled in the former were randomly selected for sampling, whereas for the EMP, we chose representative patches that we want to monitor. Another explanation for the generally higher estimates in the 2018 and 2019 EMP could be a direct result of a healthy and increasing oyster population. This has been anecdotally noted over the past 5-10 years by VIMS researchers as well as those in the aquaculture industry. Even with these differences, it is interesting to note that similar within and between-reef variation was seen in both studies.

Discussion

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 two years of data suggest that inter-annual variation is to be expected. Also, it is possible that this population has increased since the 2007/2008 study (see Ross & Luckenbach 2009), although that comparison is not rigorous due to the differences in methodology discussed above. Trends on the EMP-specific reefs moving forward should help elucidate this and help separate inter-annual variation from longer term trends.

There were some slight geographic differences noted. Higher oyster density was observed in the inlet study area (Fig. 4-2-2). This corresponds to the area that had the highest oyster settlement as well (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 a primary focus of this aspect of the EMP.

2018 & 2019 Acknowledgements

We would like to thank Edward Smith, Hunter Leonard, Jazmine Evans, Kirsten Travis, Evan Lawrence, Mary Holmes 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 2018-2019. Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

A) # m^{-2}

Study Area	Reef ID	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Q1	704	1,112	n/a	58.0	n/a
	Q2	2,016	2,096	n/a	4.0	n/a
Burton's Bay	Q4	2,048	1,272	n/a	-37.9	n/a
	Q5	624	1,432	n/a	129.5	n/a
Wach. Inlet	Q7	848	1,232	n/a	45.3	n/a
	Q9	2,592	1,888	n/a	-27.2	n/a
Average of All Regions Combined		*1,472*	*1,505*	*n/a*	*2.3*	*n/a*

B) >35 mm Biomass, g m^{-2}

Study Area	Reef ID	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Q1	97	171	n/a	76.3	n/a
	Q2	260	222	n/a	-14.6	n/a
Burton's Bay	Q4	146	165	n/a	13.0	n/a
	Q5	113	131	n/a	15.9	n/a
Wach. Inlet	Q7	168	232	n/a	38.1	n/a
	Q9	357	305	n/a	-14.6	n/a
Average of All Regions Combined		*190*	*204*	*n/a*	*7.4*	*n/a*

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

Table 4-2-2. Summary of oyster density (# m^{-2} and >35 mm g m^{-2}) at a single sentinel fringe reef in each of 3 study areas near Wachapreague, VA from 2018-2019. Comparisons of 2019 vs. 2018 are "-" (decrease), "+" (increase) and "NC" (No Change).

Study Area	Density Metric	2018	2019	Average [a] (2018-2019)	2019 vs. 2018	2019 vs. Avg. (%)
Bradford Bay (Q3)	# m^{-2}	376	104	n/a	-	n/a
	>35 mm, g m^{-2}	0	1	n/a	NC	n/a
Burton's Bay (Q6)	# m^{-2}	160	552	n/a	+	n/a
	>35 mm, g m^{-2}	0	99	n/a	+	n/a
Wach. Inlet (Q9)	# m^{-2}	1,440	496	n/a	-	n/a
	>35 mm, g m^{-2}	2	32	n/a	+	n/a
Average of All Regions Combined	*# m^{-2}*	*659*	*384*	*n/a*	-	*n/a*
	>35 mm, g m^{-2}	*1*	*44*	*n/a*	+	*n/a*

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

Table 4-2-3. Summary of oyster size classes (mean # m^{-2}) at a two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2019.

Study Area	Reef ID	Size Class	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Q1	Spat (<35 mm)	368	616	n/a	67.4	n/a
		Small (35-74 mm)	208	360	n/a	73.1	n/a
		Market (>74 mm)	128	128	n/a	0.0	n/a
	Q2	Spat (<35 mm)	1,080	1,320	n/a	22.2	n/a
		Small (35-74 mm)	656	632	n/a	-3.7	n/a
		Market (>74 mm)	272	112	n/a	-58.8	n/a
Burton's Bay	Q4	Spat (<35 mm)	1,352	616	n/a	-54.4	n/a
		Small (35-74 mm)	584	568	n/a	-2.7	n/a
		Market (>74 mm)	96	88	n/a	-8.3	n/a
	Q5	Spat (<35 mm)	312	960	n/a	207.7	n/a
		Small (35-74 mm)	264	432	n/a	63.6	n/a
		Market (>74 mm)	48	32	n/a	-33.3	n/a
Wach. Inlet	Q7	Spat (<35 mm)	376	648	n/a	72.3	n/a
		Small (35-74 mm)	416	496	n/a	19.2	n/a
		Market (>74 mm)	56	80	n/a	42.9	n/a
	Q9	Spat (<35 mm)	1,344	1,088	n/a	-19.0	n/a
		Small (35-74 mm)	888	672	n/a	-24.3	n/a
		Market (>74 mm)	360	128	n/a	-64.4	n/a

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

Table 4-2-4. Summary of oyster size classes (%) at a two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2019.

Study Area		Size Class	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Q1	Spat (<35 mm)	52.3	55.8	n/a	6.7	n/a
		Small (35-74 mm)	29.5	32.6	n/a	10.4	n/a
		Market (>74 mm)	18.2	11.6	n/a	-36.2	n/a
	Q2	Spat (<35 mm)	53.8	64.0	n/a	18.9	n/a
		Small (35-74 mm)	32.7	30.6	n/a	-6.3	n/a
		Market (>74 mm)	13.5	5.4	n/a	-59.9	n/a
Burton's Bay	Q4	Spat (<35 mm)	66.5	48.4	n/a	-27.2	n/a
		Small (35-74 mm)	28.7	44.7	n/a	55.4	n/a
		Market (>74 mm)	4.7	6.9	n/a	46.4	n/a
	Q5	Spat (<35 mm)	50.0	67.4	n/a	34.8	n/a
		Small (35-74 mm)	42.3	30.3	n/a	-28.3	n/a
		Market (>74 mm)	7.7	2.2	n/a	-70.8	n/a
Wach. Inlet	Q7	Spat (<35 mm)	44.3	52.9	n/a	19.4	n/a
		Small (35-74 mm)	49.1	40.5	n/a	-17.4	n/a
		Market (>74 mm)	6.6	6.5	n/a	-1.0	n/a
	Q9	Spat (<35 mm)	51.9	57.6	n/a	11.1	n/a
		Small (35-74 mm)	34.3	35.6	n/a	3.9	n/a
		Market (>74 mm)	13.9	6.8	n/a	-51.2	n/a

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

Table 4-2-5. Summary of oyster size classes in terms of a) mean # m^{-2} and b) % at a two sentinel patch reefs in each of 3 study areas near Wachapreague, VA from 2018-2019.

A) # m^{-2}

Study Area	Size Class	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Spat (<35 mm)	724	968	n/a	33.7	n/a
	Small (35-74 mm)	432	496	n/a	14.8	n/a
	Market (>74 mm)	200	120	n/a	-40.0	n/a
	All	*1,356*	*1,584*	*n/a*	*16.8*	*n/a*
Burton's Bay	Spat (<35 mm)	832	788	n/a	-5.3	n/a
	Small (35-74 mm)	424	500	n/a	17.9	n/a
	Market (>74 mm)	72	60	n/a	-16.7	n/a
	All	*1,328*	*1,348*	*n/a*	*1.5*	*n/a*
Wach. Inlet	Spat (<35 mm)	860	868	n/a	0.9	n/a
	Small (35-74 mm)	652	584	n/a	-10.4	n/a
	Market (>74 mm)	208	104	n/a	-50.0	n/a
	All	*1,720*	*1,556*	*n/a*	*-9.5*	*n/a*

B) %

Study Area	Size Class	2018	2019	Average [a] (2018-2019)	2019 vs. 2018 (%)	2019 vs. Avg. (%)
Bradford Bay	Spat (<35 mm)	53.4	61.1	n/a	14.5	n/a
	Small (35-74 mm)	31.9	31.3	n/a	-1.7	n/a
	Market (>74 mm)	14.7	7.6	n/a	-48.6	n/a
Burton's Bay	Spat (<35 mm)	62.7	58.5	n/a	-6.7	n/a
	Small (35-74 mm)	31.9	37.1	n/a	16.2	n/a
	Market (>74 mm)	5.4	4.5	n/a	-17.9	n/a
Wach. Inlet	Spat (<35 mm)	50.0	55.8	n/a	11.6	n/a
	Small (35-74 mm)	37.9	37.5	n/a	-1.0	n/a
	Market (>74 mm)	12.1	6.7	n/a	-44.7	n/a

[a] Since only two years of data have been collected, averages for years have been noted as "n/a", although we plan to start calculating this once a third year of data is collected (2020).

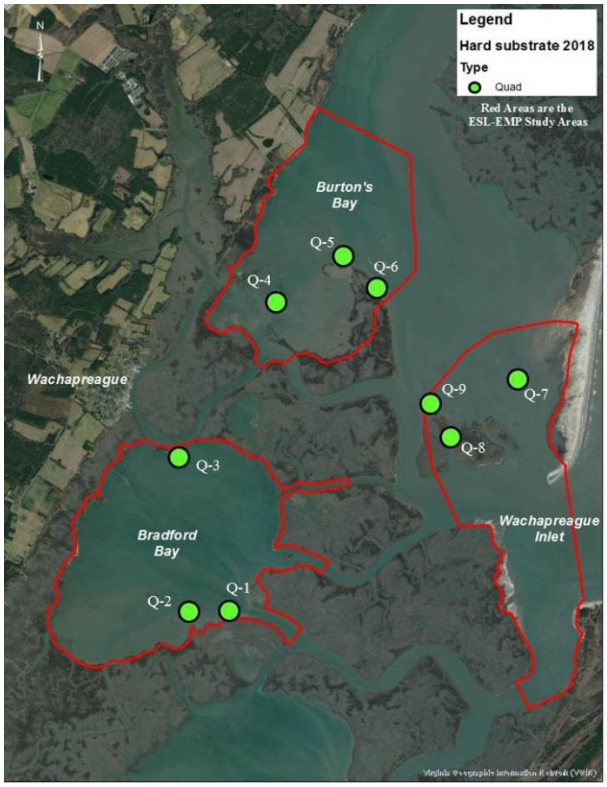


Fig. 4-2-1 Locations of 9 intertidal oyster reef monitoring sites near Wachapreague, VA for 2018 (red polygons denote the ESL-EMP study areas).

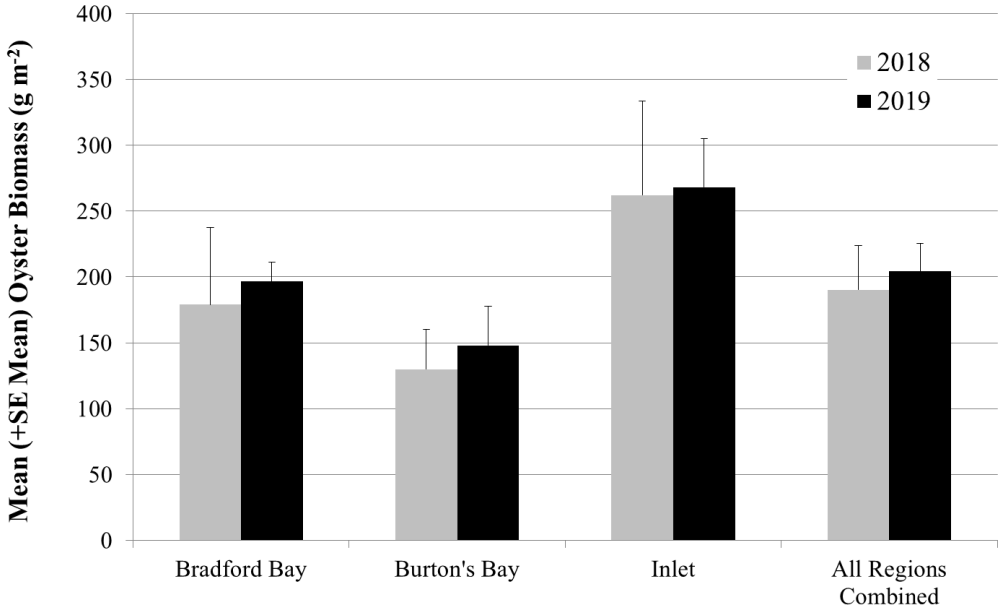


Fig. 4-2-2 Mean (+ SE) oyster biomass (ash-free dry wt.; g m^{-2}) at intertidal patch reefs in three geographic areas (and those regions combined) near Wachapreague, VA during 2018-2019.

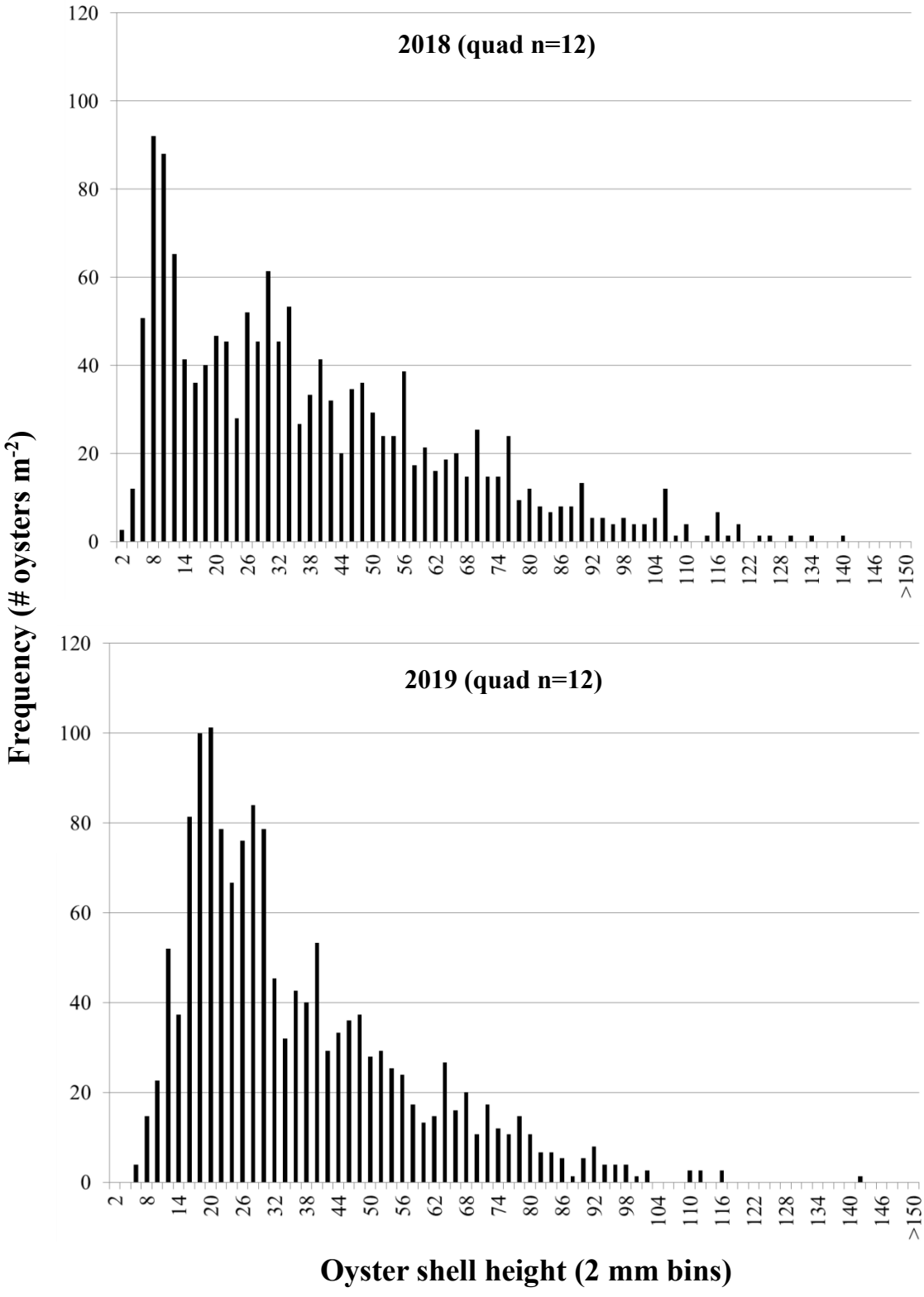


Fig. 4-2-3 Pooled size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found on intertidal monitoring patch reefs only near Wachapreague, VA in 2018 & 2019.

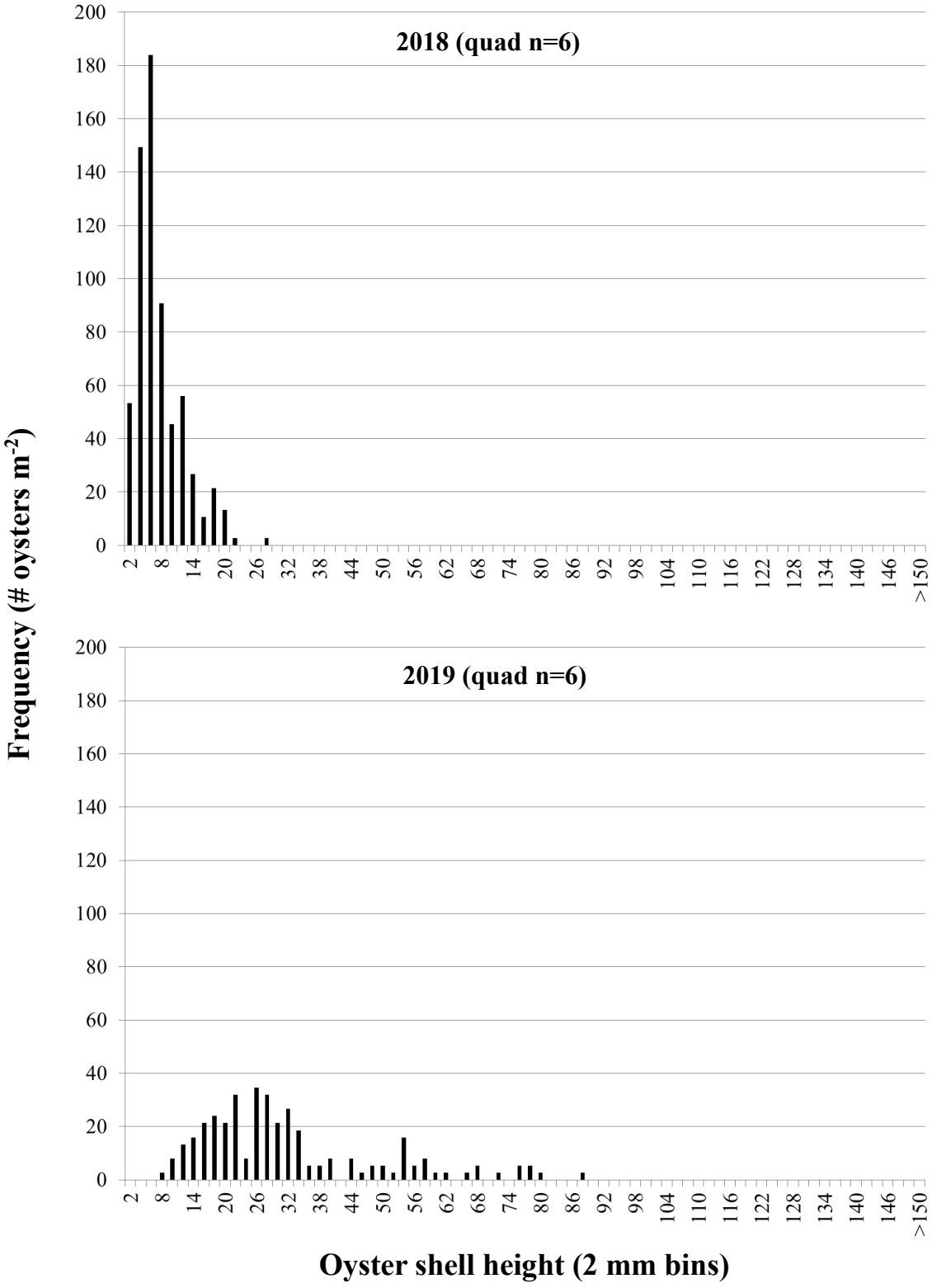


Fig. 4-2-4 Pooled size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found on intertidal monitoring fringe reefs only near Wachapreague, VA in 2018 & 2019.

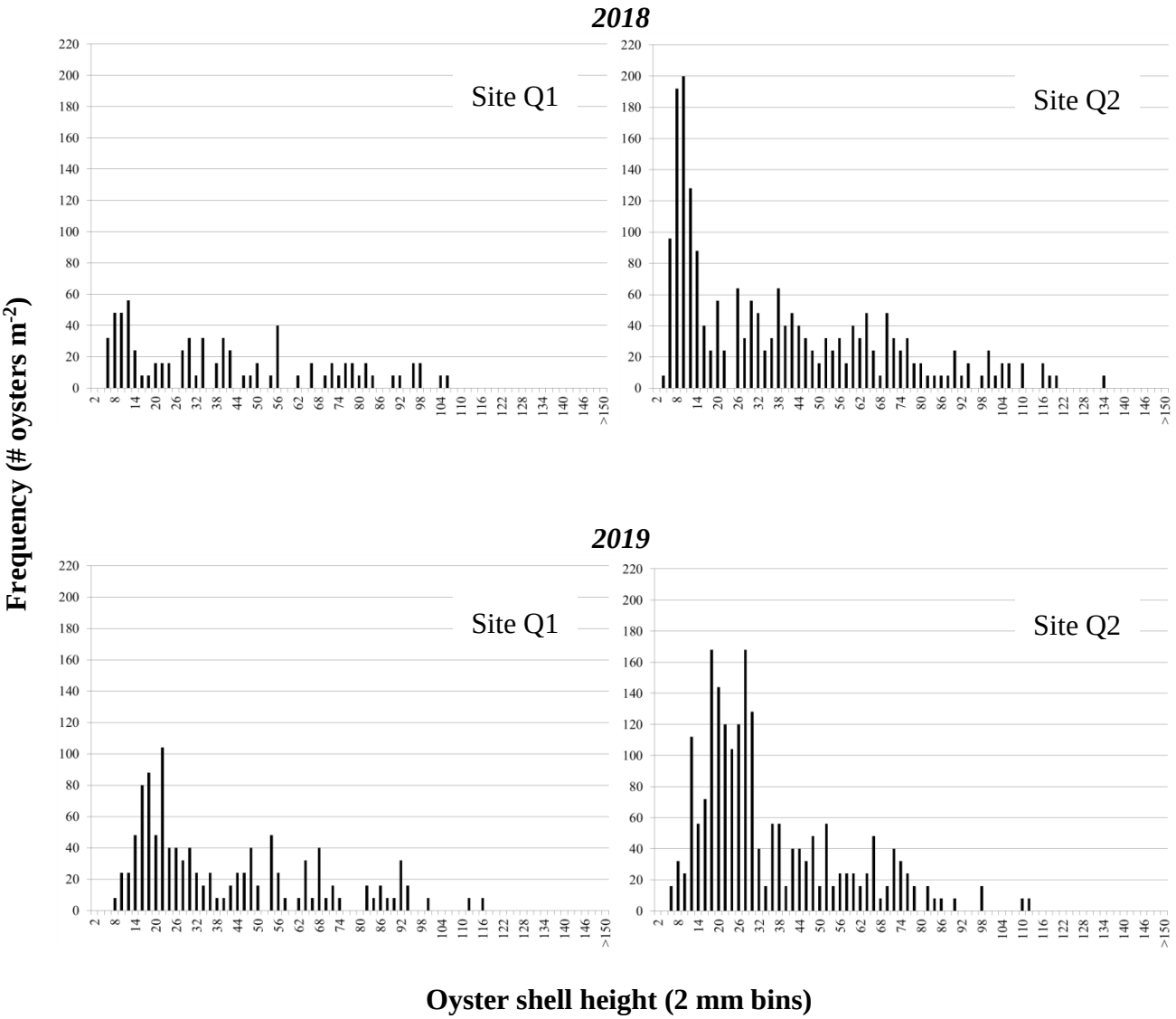


Fig. 4-2-5 Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs in Bradford Bay (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018 & 2019.

Appendix 4-2-1. Summary of oyster density (# m^{-2}) and ash-free dry tissue biomass (g m^{-2}; oysters ≥ 35 mm) for individual sub-samples of intertidal patch and fringe reefs sampled within three regions near Wachapreague, VA during summer 2018-2019.

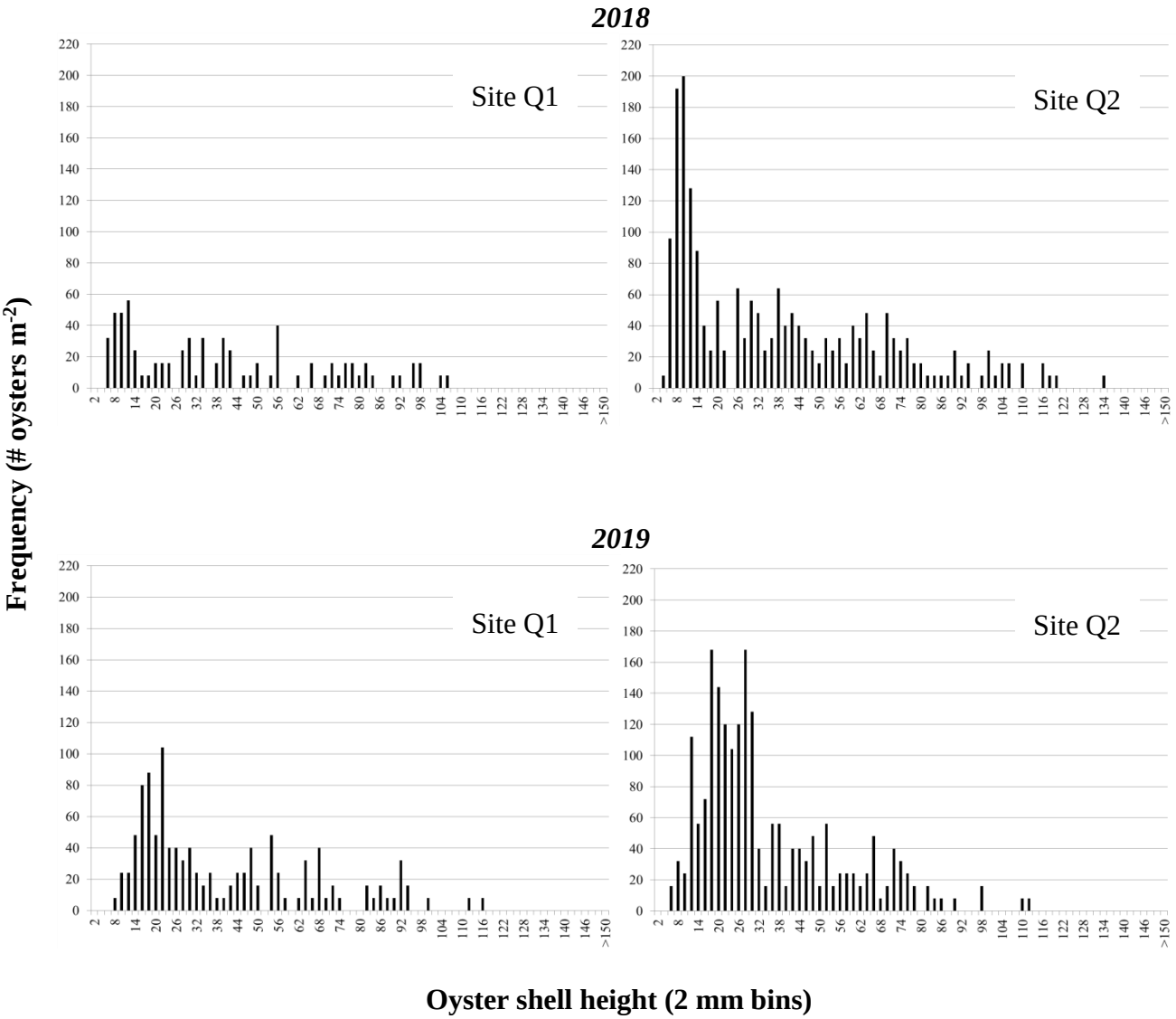
2018

Region	Reef Type	Sample ID	Density # m^{-2}			>35 mm Dry Tissue Biomass (g m^{-2})		
			Crest Subsample	Flank Subsample	Mean Crest + Flank	Crest Subsample	Flank Subsample	Mean Crest + Flank
Bradford Bay	Patch	Q1	992	416	*704*	183	12	*97*
		Q2	2,128	1,904	*2,016*	250	271	*260*
	Fringe	Q3	0	752	*376*	0	0	*0*
Burton's Bay	Patch	Q4	3,328	768	*2,048*	194	98	*146*
		Q5	672	576	*624*	166	61	*113*
	Fringe	Q6	16	304	*160*	0	0	*0*
Inlet	Patch	Q7	1,408	288	*848*	259	76	*168*
		Q9	2,272	2,912	*2,592*	293	420	*357*
	Fringe	Q8	368	2,512	*1,440*	4	0	*2*

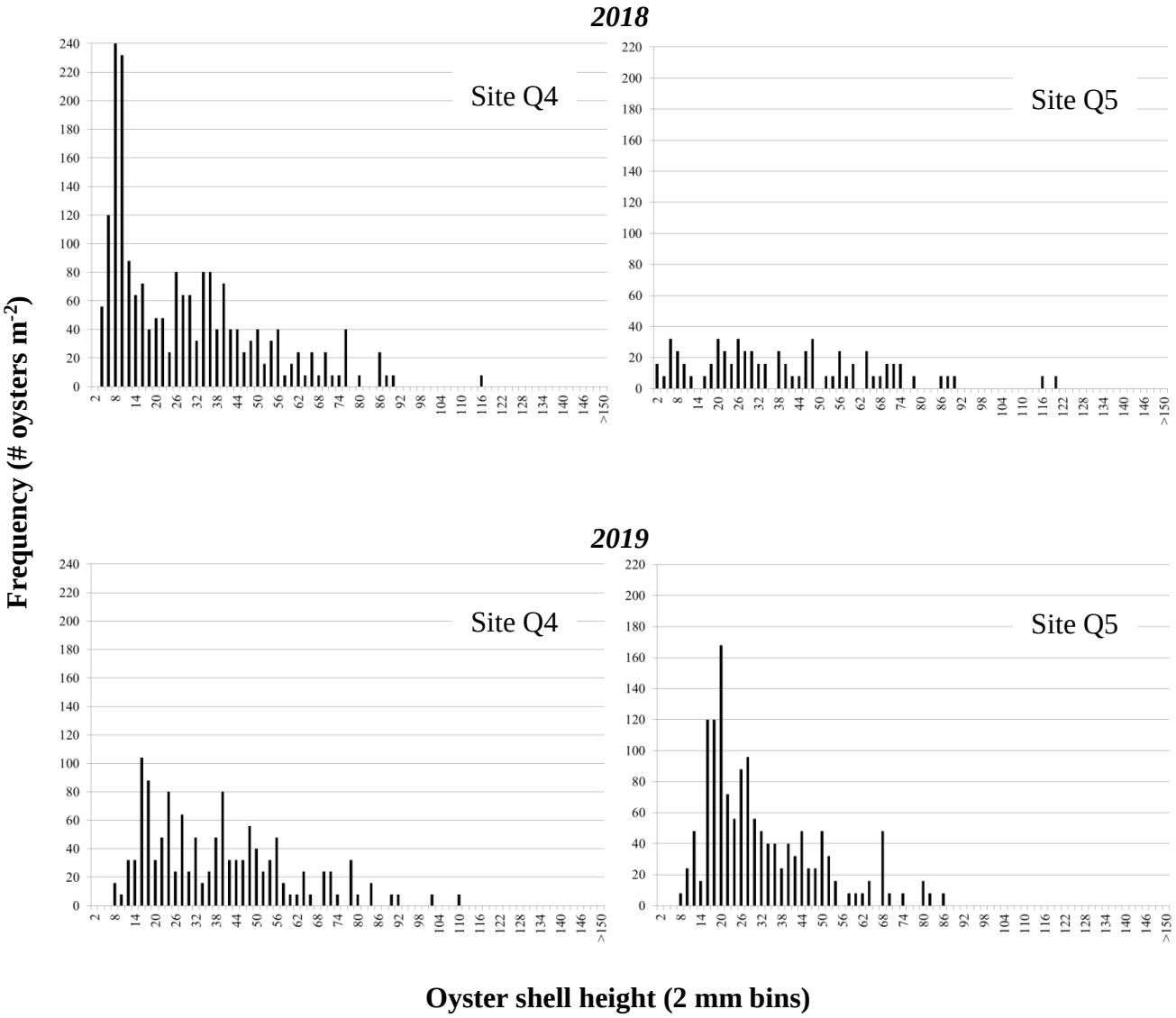
2019

Region	Reef Type	Sample ID	Density # m^{-2}			>35 mm Dry Tissue Biomass (g m^{-2})		
			Crest Subsample	Flank Subsample	Mean Crest + Flank	Crest Subsample	Flank Subsample	Mean Crest + Flank
Bradford Bay	Patch	Q1	1,184	1,040	*1,112*	180	163	*172*
		Q2	2,496	1,696	*2,096*	222	222	*222*
	Fringe	Q3	208	0	*104*	2	0	*1*
Burton's Bay	Patch	Q4	1,136	1,408	*1,272*	107	224	*166*
		Q5	992	1,872	*1,432*	94	168	*131*
	Fringe	Q6	400	704	*552*	51	147	*99*
Inlet	Patch	Q7	960	1,504	*1,232*	292	171	*232*
		Q9	1,456	2,320	*1,888*	262	347	*305*
	Fringe	Q8	928	64	*496*	33	31	*32*

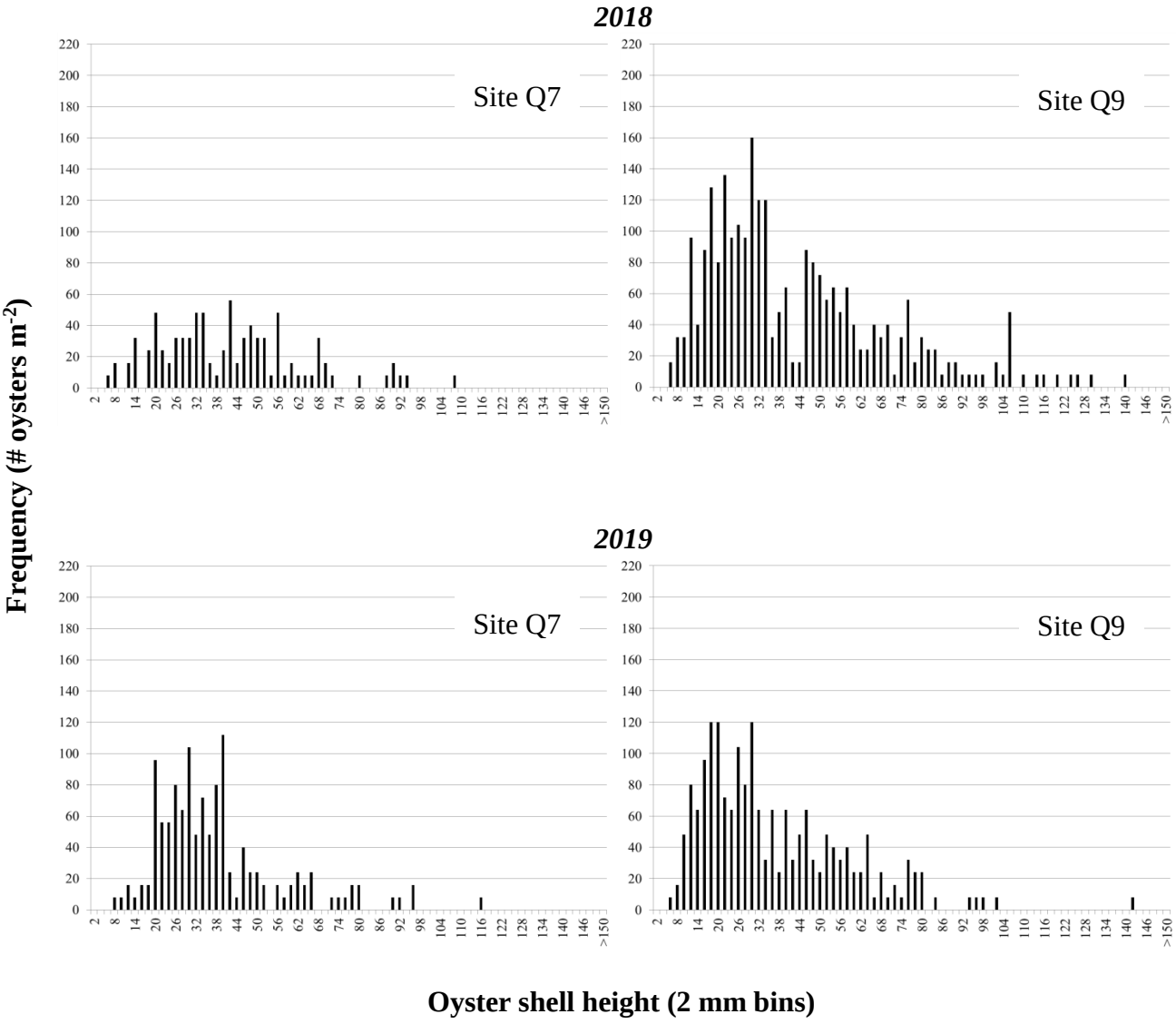
Appendix 4-2-2. Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs in Bradford Bay (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018 & 2019.



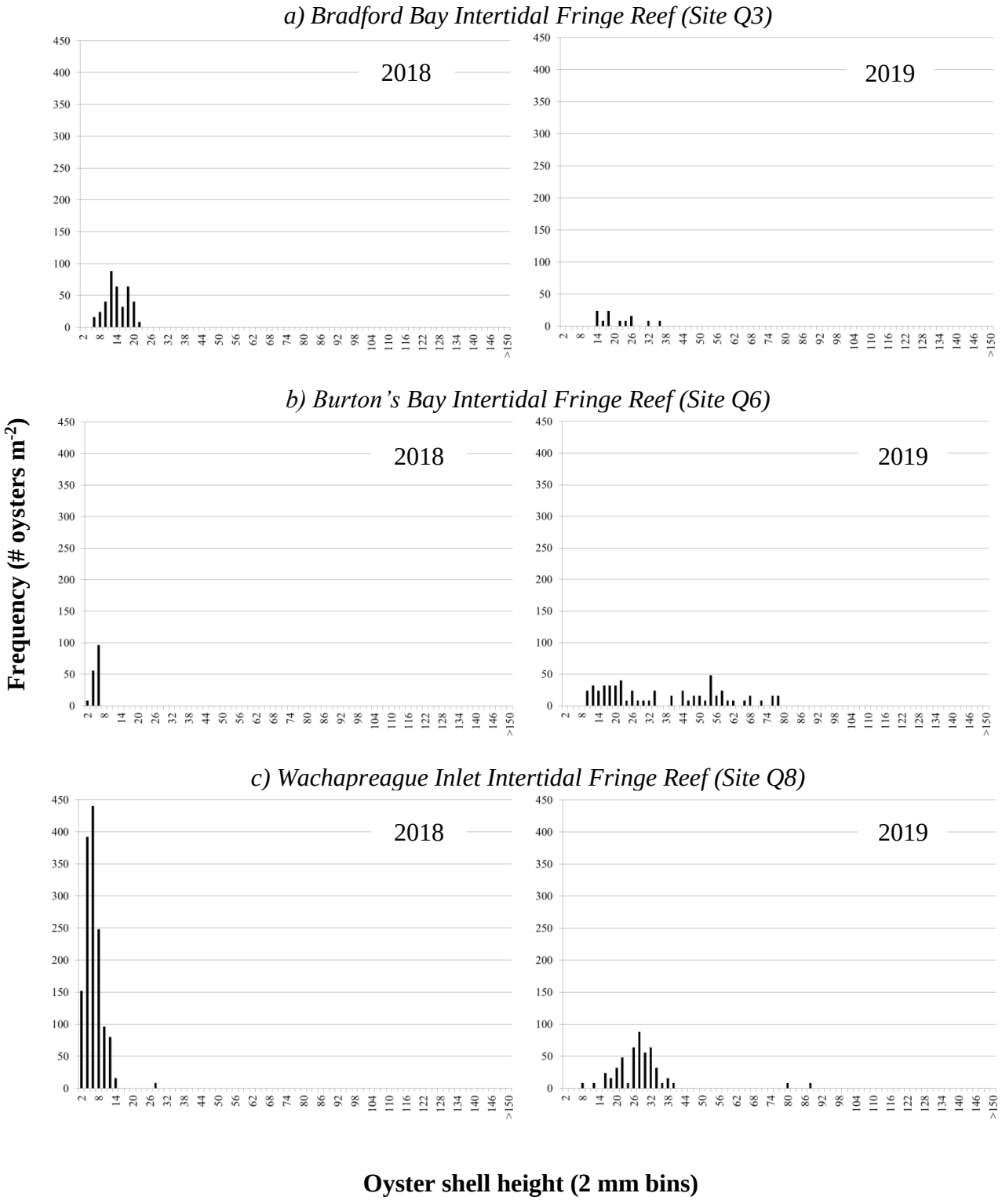
Appendix 4-2-3. Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at two intertidal patch reefs in Burtons Bay (see Fig. 4-2-1 for locations) near Wachapreague, VA during 2018 & 2019.



Appendix 4-2-4. 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 & 2019.



Appendix 4-2-5. Size frequency distribution (# oysters m^{-2} in 2 mm size bins) of oysters found at intertidal fringe reefs in three geographic areas (see Fig. 4-2-1) near Wachapreague, VA: a) Bradford Bay, b) Burton's Bay and c) Wachapreague Inlet.



Chapter 5. Epi-benthic Community

Section 5-1: Benthic Soft Sediment Community

Authors: PG Ross

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Planned	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. 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. Therefore, monitoring these habitats and their associated communities are priorities for the EMP.

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 in 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). The grab sampled a 0.0841 m^2 area to a depth of 10-15 cm. The 6.35 cm diameter push core sampled a 0.0032 m^2 area to a depth of 15 cm.

Grab samples (n=27 and n=30 in 2018 and 2019, respectively) and cores (n=81 and n=63 in 2018 and 2019, respectively) were distributed in three geographic areas (Figs. 5-1-2 & 5-1-3). 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 June 5 and July 20 in 2018 and between May 6 and

May 24 in 2019. Future sampling will target this mid-May to end of June time period for consistency between years.

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.

Surface sediment samples were also secured at all grab and core sites by taking the top 1 cm for determining organic matter and chlorophyll-a content. Samples were also collected at the 27 grab sites to describe particle size fractions at 0-5, 5-10 and 10-15 cm depths. This data is reported in Chapter 6-3 of this report.

2018 & 2019 Results

In total, 1,137 and 1,492 individual organisms were sampled during 2018 and 2019, respectively representing >60 and >80 genera, respectively. The total ash-free dry biomass of the organisms collected was 31.5 g and 42.5 g in 2018 and 2019, respectively (Table 5-1-2). Polychaetes, gastropods, amphipods and bivalve mollusks dominated SSC by density (# m^{-2}), while those groups and macroalgae dominated in terms of biomass (g m^{-2}; Tables 5-1-3 & 5-1-4). Slight 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 for both years is summarized in Table 5-1-9. The overall density of organisms sampled was 449.4 and 547.6 m^{-2} during 2018 and 2019, respectively. The total biomass density of these organisms also increased in 2019 over 2018 with 15.6 and 12.8 g m^{-2}, respectively.

Samples from 2019 also contained more taxa than 2018 with 70 and 59 genera, respectively (Tables 5-1-9 & 5-1-10). 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 2018 and 2019 for all study areas, but followed similar patterns between study areas within each year (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 *Ensis* and *Diodora* <10 mm were also measured. There were enough measurements for *Ensis leei* (2018 only) and *Tritia obsolete* (both years) to develop size frequency distributions that describe the population size/age structure (Figs. 5-1-5 & 5-1-6).

At this point we have chosen not to use a statistical approach to analyze the data in this section. Once we collect a third year of data, we plan to do so. 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

These were the first two formal years for the EMP. We do not have any previous comparable data for these specific sites or this area in general.

Discussion

The main objective for this portion of the EMP in 2018 and 2019 was to initially document the distribution and abundance of organisms in the system and define biomass quantities and size spectra. We also wanted to refine our sampling plan to make future work on this project more efficient. For example, we know cores were less effective at sampling some organisms, but allowed us to cover more sites. Alternatively, the larger grab samples tend to sample the community better, but are much more labor intensive to collect and process and thus limit the number of sites we can cover. However, based on the relative effort and value of these different sampling techniques in 2018 and 2019, we have substantially adjusted our planned sampling plan for 2020 to include only grab samples to collect soft-sediment community data.

Large organisms that are only occasionally sampled can significantly impact results. The 45% "Other Animals" category for Bradford Bay in 2019 is driven by several relatively large juvenile eels. Removing these epibenthic mobile species would remove a confounding effect on describing SSC, but the presence of these organisms in the samples is important to defining the dynamics of the system.

Comparing geographical areas and sub-habitats will be useful. Analysis presented above raises interesting questions regarding spatial community structure and diversity that raises questions about the factors controlling distribution and abundance of species. Analysis of the effect of abiotic factors described in other chapters (e.g. water quality and sediment characteristics) on community composition can be assessed using multivariate techniques. In addition, as the dataset grows with additional years, individual sites can be examined for stability and change dynamics of diversity and productivity over time.

Acknowledgements

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Table 5-1-1. Soft-sediment community sampling plan within three regions near Wachapreague, VA during 2018 and 2019.

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

Table 5-1-2. Summary of the total # and biomass (g) of individuals collected for broad taxa sampled in soft-sediment samples near Wachapreague, VA during summer 2018 (27 grabs and 81 cores) and 2019 (30 grabs and 63 cores). A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018		2019	
		Total #	Total Biomass (g)	Total #	Total Biomass (g)
All Taxa		*1,137*	*31.5478*	*1,492*	*42.5432*
Macroalgae					
Seaweeds	Macroalgae	+	15.7611	+	14.3684
Worms					
Polychaete worms	Polychaeta	684	7.1503	553	*5.3672*
Ribbon worms	Nemertea	6	1.1506	2	0.0332
Mollusks					
Snails	Gastropoda (snails)	166	5.6902	291	11.635
Clams	Bivalvia	69	1.4572	219	2.1794
Slipper shells	Gastropoda (slipper shells)	1	0.0006	1	0.0015
Limpets	Gastropoda (limpets)			3	0.1259
Crustaceans					
Hermit crabs	Paguridae	4	0.1264	11	0.1386
Amphipods	Amphipoda	165	0.0820	297	0.1793
Isopods	Isopoda	9	0.0236	41	0.1095
Mud Crabs	Pleocyemata (Xanthidae)	2	0.0076	17	0.4738
Shrimp	Pleocyemata (Caridea)	10	0.0075	20	0.3575
Burrowing shrimp	Pleocyemata (Axiidea)	1	0.0028	12	0.3735
Pea crabs	Brachyura (Pinnotheridae)	3	0.0023	4	0.0122
Other shrimp	Pleocyemata	3	0.0022		
Mantis shrimp	Stomatopoda	1	0.0015		
Cumaceans	Malacostraca (Cumacea)	1	0.0010	1	<0.0001
Other Animals					
Bony Fish	Osteichthyes	4	0.0292	3	4.1441
Sea cucumbers	Echinodermata			2	2.9256
Bryozoans	Bryozoa	+	0.0243		
Unknown	unknown	+	0.0106		
Anemones	Cnidaria (Actinaria)	5	0.0101	3	0.0006
Hemichordates	Hemichordata	2	0.0043	3	0.0775
Fly larvae	Diptera	1	0.0024	1	0
Worms	Oligochaeta			8	0.0403
Sea spiders	Pycnogonida (sea spider)	1	<0.0001		

Table 5-1-3. Summary of the total density (# m^{-2}) of broad taxa collected in soft-sediment samples pooled for the three study areas near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*449.4*	*547.6*
Macroalgae			
Seaweeds	Macroalgae	+	+
Worms			
Polychaete worms	Polychaeta	270.4	203.0
Ribbon worms	Nemertea	2.4	0.7
Mollusks			
Snails	Gastropoda (snails)	65.6	106.8
Clams	Bivalvia	27.3	80.4
Slipper shells	Gastropoda (slipper shells)	0.4	0.4
Limpets	Gastropoda (limpets)		1.1
Crustaceans			
Hermit crabs	Paguridae	1.6	4.0
Amphipods	Amphipoda	65.2	109.0
Isopods	Isopoda	3.6	15.0
Mud Crabs	Pleocyemata (Xanthidae)	0.4	6.2
Shrimp	Pleocyemata (Caridea)	4.0	7.3
Burrowing shrimp	Pleocyemata (Axiidea)	0.4	4.4
Pea crabs	Brachyura (Pinnotheridae)	1.2	1.5
Other shrimp	Pleocyemata	1.2	
Mantis shrimp	Stomatopoda	0.4	
Cumaceans	Malacostraca (Cumacea)	0.4	0.4
Other Animals			
Bony Fish	Osteichthyes	1.6	1.1
Sea cucumbers	Echinodermata		0.7
Bryozoans	Bryozoa	+	
Unknown	unknown	+	
Anemones	Cnidaria (Actinaria)	2.0	1.1
Hemichordates	Hemichordata	0.8	1.1
Fly larvae	Diptera	0.4	0.4
Worms	Oligochaeta		2.9
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 the three study areas near Wachapreague, VA during summer 2018-2019. A blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*12.4701*	*15.6145*
Macroalgae			
Seaweeds	Macroalgae	6.2299	5.2736
Worms			
Polychaete worms	Polychaeta	2.8263	1.9699
Ribbon worms	Nemertea	0.4548	0.0122
Mollusks			
Snails	Gastropoda (snails)	2.2492	4.2704
Clams	Bivalvia	0.5760	0.7999
Slipper shells	Gastropoda (slipper shells)	0.0002	0.0006
Limpets	Gastropoda (limpets)		0.0462
Crustaceans			
Hermit crabs	Paguridae	0.0500	0.0509
Amphipods	Amphipoda	0.0325	0.0658
Isopods	Isopoda	0.0093	0.0402
Mud Crabs	Pleocyemata (Xanthidae)	0.0030	0.1739
Shrimp	Pleocyemata (Caridea)	0.0030	0.1312
Burrowing shrimp	Pleocyemata (Axiidea)	0.0011	0.1371
Pea crabs	Brachyura (Pinnotheridae)	0.0009	0.0045
Other shrimp	Pleocyemata	0.0009	
Mantis shrimp	Stomatopoda	0.0006	
Cumaceans	Malacostraca (Cumacea)	0.0004	0.0000
Other Animals			
Bony Fish	Osteichthyes	0.0115	1.5210
Sea cucumbers	Echinodermata	0.0000	1.0738
Bryozoans	Bryozoa	0.0096	
Unknown	unknown	0.0042	
Anemones	Cnidaria (Actinaria)	0.0040	0.0002
Hemichordates	Hemichordata	0.0017	0.0284
Fly larvae	Diptera	0.0009	0.0000
Worms	Oligochaeta		0.0148
Sea spiders	Pycnogonida (sea spider)	<0.00010	

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 2018-2019. A blank cell indicates the absence of that taxon.

Representative Taxonomic Grouping	Geographic Area	2018	2019
All Taxa Combined	*All 3 Areas*	*12.4701*	*15.6145*
All Taxa Combined	Bradford Bay	12.3345	13.9708
	Burton's Bay	17.2472	26.4763
	Wach. Inlet	7.8284	6.3963
Macroalgae (Seaweeds)	Bradford Bay	5.7233	3.7211
	Burton's Bay	10.5071	11.8216
	Wach. Inlet	2.4594	
Worms	Bradford Bay	5.0218	3.2501
	Burton's Bay	3.9349	2.0834
	Wach. Inlet	0.8866	0.6129
Mollusks (Snails, clams, etc.)	Bradford Bay	1.4982	1.0440
	Burton's Bay	2.7590	9.1209
	Wach. Inlet	4.2190	5.1861
Crustaceans (Crabs, shrimp, amphipods etc.)	Bradford Bay	0.0574	1.3442
	Burton's Bay	0.0375	0.1911
	Wach. Inlet	0.2100	0.2753
Other Animals (Fish, echinoderms, anenomes etc.)	Bradford Bay	0.0338	4.6113
	Burton's Bay	0.0087	3.2593
	Wach. Inlet	0.0532	0.0440

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 2018-2019. A blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*12.3345*	*13.9708*
Macroalgae			
Seaweeds	Macroalgae	5.7233	3.7211
Worms			
Polychaete worms	Polychaeta	4.9158	3.2501
Ribbon worms	Nemertea	0.1060	
Mollusks			
Snails	Gastropoda (snails)	0.7243	0.7188
Clams	Bivalvia	0.7739	0.1850
Slipper shells	Gastropoda (slipper shells)		0.0017
Limpets	Gastropoda (limpets)		0.1386
Crustaceans			
Hermit crabs	Paguridae		0.0693
Amphipods	Amphipoda	0.0243	0.0154
Isopods	Isopoda	0.0098	0.1087
Mud Crabs	Pleocyemata (Xanthidae)	0.0090	0.4703
Shrimp	Pleocyemata (Caridea)	0.0052	0.2943
Burrowing shrimp	Pleocyemata (Axiidea)	0.0033	0.3844
Pea crabs	Brachyura (Pinnotheridae)	0.0027	0.0019
Other shrimp	Pleocyemata		
Mantis shrimp	Stomatopoda	0.0018	
Cumaceans	Malacostraca (Cumacea)	0.0012	<0.0001
Other Animals			
Bony Fish	Osteichthyes	0.0212	4.4816
Sea cucumbers	Echinodermata		
Bryozoans	Bryozoa		
Unknown	unknown	0.0126	
Anemones	Cnidaria (Actinaria)		<0.0001
Hemichordates	Hemichordata		0.0853
Fly larvae	Diptera		
Worms	Oligochaeta		0.0444
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 2018-2019. A blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*17.2472*	*26.6658*
Macroalgae			
Seaweeds	Macroalgae	10.5071	11.8216
Worms			
Polychaete worms	Polychaeta	2.9162	2.0834
Ribbon worms	Nemertea	1.0187	
Mollusks			
Snails	Gastropoda (snails)	2.6483	8.3076
Clams	Bivalvia	0.1100	0.8133
Slipper shells	Gastropoda (slipper shells)	0.0007	
Limpets	Gastropoda (limpets)		
Crustaceans			
Hermit crabs	Paguridae		0.0068
Amphipods	Amphipoda	0.0208	0.1343
Isopods	Isopoda	0.0130	0.0116
Mud Crabs	Pleocyemata (Xanthidae)		0.0146
Shrimp	Pleocyemata (Caridea)	0.0037	0.0197
Burrowing shrimp	Pleocyemata (Axiidea)		0.0034
Pea crabs	Brachyura (Pinnotheridae)		0.0007
Other shrimp	Pleocyemata		
Mantis shrimp	Stomatopoda		
Cumaceans	Malacostraca (Cumacea)		
Other Animals			
Bony Fish	Osteichthyes	0.0008	0.0373
Sea cucumbers	Echinodermata		3.2213
Bryozoans	Bryozoa		
Unknown	unknown		
Anemones	Cnidaria (Actinaria)	<0.0001	0.0007
Hemichordates	Hemichordata	0.0050	
Fly larvae	Diptera	0.0028	
Worms	Oligochaeta		
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 Inet study area near Wachapreague, VA during summer 2018-2019. A blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*7.8284*	*6.2068*
Macroalgae			
Seaweeds	Macroalgae	2.4594	
Worms			
Polychaete worms	Polychaeta	0.6470	0.5763
Ribbon worms	Nemertea	0.2397	0.0366
Mollusks			
Snails	Gastropoda (snails)	3.3750	3.7846
Clams	Bivalvia	0.8441	1.4015
Slipper shells	Gastropoda (slipper shells)		
Limpets	Gastropoda (limpets)		
Crustaceans			
Hermit crabs	Paguridae	0.1499	0.0765
Amphipods	Amphipoda	0.0524	0.0477
Isopods	Isopoda	0.0051	0.0003
Mud Crabs	Pleocyemata (Xanthidae)		0.0368
Shrimp	Pleocyemata (Caridea)		0.0796
Burrowing shrimp	Pleocyemata (Axiidea)		0.0235
Pea crabs	Brachyura (Pinnotheridae)		0.0109
Other shrimp	Pleocyemata	0.0026	
Mantis shrimp	Stomatopoda		
Cumaceans	Malacostraca (Cumacea)		
Other Animals			
Bony Fish	Osteichthyes	0.0126	0.0440
Sea cucumbers	Echinodermata		
Bryozoans	Bryozoa	0.0288	
Unknown	unknown		
Anemones	Cnidaria (Actinaria)	0.0119	
Hemichordates	Hemichordata	<0.0001	
Fly larvae	Diptera		<0.0001
Worms	Oligochaeta		
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 2018-2019. 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**	**2018**	**2019**
All Taxa	*449.4*	*547.6*	*12.4701*	*15.6145*
Amphipoda	65.2	109.0	0.0325	0.0658
Ampelisca	30.0	7.7	0.0106	0.0051
Ampithoe	5.5	1.1	0.0022	0.0013
Apocorophium	0.4		0.0002	
Caprella	0.8		0.0002	
Corophium	2.4	3.3	0.0011	0.0004
Gammarus	11.5	79.6	0.0077	0.0491
Haustorid		3.7		0.0050
Idunella		1.1		0.0001
Lysianopsis		6.6		0.0019
Melita	2.4	4.4	0.0008	0.0023
Paracaprella		0.7		0.0001
Unidentified amphipod	12.3	0.7	0.0098	0.0004
Bivalvia	27.3	80.4	0.5760	0.7999
Anadara		1.1		0.0018
Ensis	0.4	28.6	0.0082	0.6040
Gemma	3.6		0.0004	
Limecola	1.6	3.3	0.0014	0.0115
Macoploma	12.3	20.6	0.0342	0.0596
Mercenaria	2.0		0.0473	
Mulinia	1.6	21.7	0.0016	0.0172
Mya	3.2	0.7	0.0045	0.0004
Spisula		0.4		
Tagelus	2.4	4.0	0.4770	0.1054
Yoldia	0.4		0.0013	
Brachyura (Pinnotheridae)	1.2	1.5	0.0009	0.0045
Pinnixa		1.5		0.0045
Pinnixulala	1.2		0.0009	
Bryozoa	+		0.0096	
Bugula	+		0.0096	

Table continued on next page

Table 5-1-9 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	2019	2018	2019
Cnidaria (Actinaria)	2.0	1.1	0.0040	0.0002
Diadumene	2.0	0.7	0.0040	0.0002
Edwardsiella		0.4		<0.0001
Diptera	0.4	0.4	0.0009	
Diptera	0.4	0.4	0.0009	
Echinodermata		0.7		1.0738
Sclerodactyla		0.7		1.0738
Gastropoda (limpets)		1.1		0.0462
Diodora		1.1		0.0462
Gastropoda (slipper shells)	0.4	0.4	0.0002	0.0006
Crepidula	0.4	0.4	0.0002	0.0006
Gastropoda (snails)	65.6	106.8	2.2492	4.2704
Acteocina	2.4	4.8	0.0011	0.0040
Astyris	0.8	2.9	0.0005	0.0087
Busycotypus	0.4		0.1589	
Epitonium		0.4		0.0005
Haminella		26.1		0.0541
Nucella		0.4		0.0005
Phrontis	1.6		0.0018	
Seila	0.4	0.4	0.0003	0.0006
Tritia	58.9	71.9	2.0865	4.2020
Turbonilla	1.2		<0.0001	
Hemichordata	0.8	1.1	0.0017	0.0284
Saccoglossus	0.8	1.1	0.0017	0.0284
Isopoda	3.6	15.0	0.0093	0.0402
Cyathura	1.2	12.8	0.0033	0.0395
Edotea		2.2		0.0007
Edotia	0.4		0.0000	
Erichsonella	1.6		0.0035	
Idotea	0.4		0.0025	
Macroalgae	+	+	6.2299	5.2736
Gracilariopsis	+	+	3.0503	0.6675
Ulva	+	+	3.1796	4.6061
Malacostraca	0.4	0.4	0.0004	<0.0001
Cumacea	0.4	0.4	0.0004	<0.0001
Nemertea	2.4	0.7	0.4548	0.0122
Micrura	2.4	0.7	0.4548	0.0122

Table continued on next page

Table 5-1-9 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	**2019**	**2018**	**2019**
Oligochaeta		2.9		0.0148
Oligochaeta		2.9		0.0148
Osteichthyes	1.6	1.1	0.0115	1.5210
Anguilla		0.4		1.4939
Conger		0.7		0.0271
Gobiosoma	1.6		0.0115	
Paguridae	1.6	4.0	0.0500	0.0509
Pagurus	1.6	4.0	0.0500	0.0509
Pleocyemata	1.2		0.0009	
Unidentifed crab	1.2		0.0009	
Pleocyemata (Axiidea)	0.4	4.4	0.0011	0.1371
Biffarius	0.4	3.3	0.0011	0.0088
Upogebia		1.1		0.1282
Pleocyemata (Caridea)	4.0	7.3	0.0030	0.1312
Alpheus		1.5		0.1064
Crangon		0.4		0.0004
Ogyrides	3.2	5.5	0.0026	0.0244
Unidentified shrimp	0.8		0.0004	
Pleocyemata (Xanthidae)	0.4	6.2	0.0030	0.1739
Dyspanopeus		0.4		0.0104
Eurypanopeus		4.0		0.0473
Panopeus	0.4	1.8	0.0030	0.1163
Polychaeta	270.4	203.0	2.8263	1.9699
Alitta	204.0	129.6	1.9320	1.1961
Arabella	1.6	1.8	0.0815	0.0742
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	0.0775	0.0709
Diopatra	2.4	1.5	0.0910	0.0552
Drilonereis	24.1	33.0	0.0515	0.0546
Eteone	0.4		0.0029	
Glycera	7.1	9.9	0.3479	0.0881
Lepidonotus	0.4		0.0062	
Lumbrineris	0.4	0.4	<0.0001	0.0002
Maldane	1.6	1.1	0.0044	0.0099

Table continued on next page

Table 5-1-9 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	**2019**	**2018**	**2019**
Polychaeta (cont.)				
Marphysa	2.8	4.4	0.0864	0.1607
Nephtys		2.2		0.0050
Onuphis		0.4		0.0003
Orbinidae		0.7		0.0008
Pectinaria	0.4	1.1	0.0009	0.0070
Phyllodoce		1.1		0.0019
Piromis		0.7		0.0046
Spiochaetopterus	4.3	1.1	0.0108	0.0008
Sthenelais		0.4		0.0210
Unidentified polychaete	0.8	0.7	0.1321	0.1550
Pycnogonida	0.4		<0.0001	
Nymphon	0.4		<0.0001	
Stomatopoda	0.4		0.0006	
Squilla	0.4		0.0006	

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 2018-2019.

Community Metric	Geographic Area	2018	2019
Abundance (# m^{-2})	Bradford Bay	583	616
	Burton's Bay	443	723
	Wach. Inlet	321	304
	Overall	*449*	*548*
Taxa Richness	Bradford Bay	36	44
	Burton's Bay	37	45
	Wach. Inlet	38	39
	Overall	*59*	*70*
Shannon Diversity Index (H')	Bradford Bay	1.50	2.45
	Burton's Bay	2.16	2.49
	Wach. Inlet	2.66	2.73
	Overall	*2.30*	*2.86*

Table 5-1-11. Summary of sizes (mm using species-specific standard measurements) of species that were measured from samples collected in soft-sediment samples near Wachapreague, VA during 2018-2019. 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			
	# < 10 mm	# ≥ 10 mm*	Range (mm)	Avg (mm)	# < 10 mm	# ≥ 10 mm*	Range (mm)	Avg (mm)
Bivalvia (non-Crassostrea)								
Ensis leei	n/a*	1	28-28	28.0	n/a*	77	5-39	27.0
Limecola balthica	4				9	2	10-10	10.0
Macoploma tenta	28	3	16-20	17.3	37	19	10-13	11.2
Mercenaria mercenaria	4	1	21-21	21.0				
Tagelus plebius	0	4	13-65	38.8	0	9	16-24	20.6
Gastropoda (limpets)								
Diodora cayenensis					n/a*	3	7-24	13.0
Gastropoda (snails)								
Busycotypus canaliculatus	0	1	43-43	43.0				
Tritia obsoleta	0	72	10-24	17.4	0	190	10-26	17.9
Osteichthyes								
Conger oceanicus					0	1	58-58	58.0
Gobiosoma bosc	0	2	19-19	19.0				
Pleocyemata (Xanthidae)								
Eurypanopeus depressus					0	1	14-14	14.0
Panopeus herbstii					0	4	10-17	12.8

* Snails, xanthid mud crabs and most bivalve species were only measured if ≥10 mm (*Ensis* & *Diodora* were exceptions)

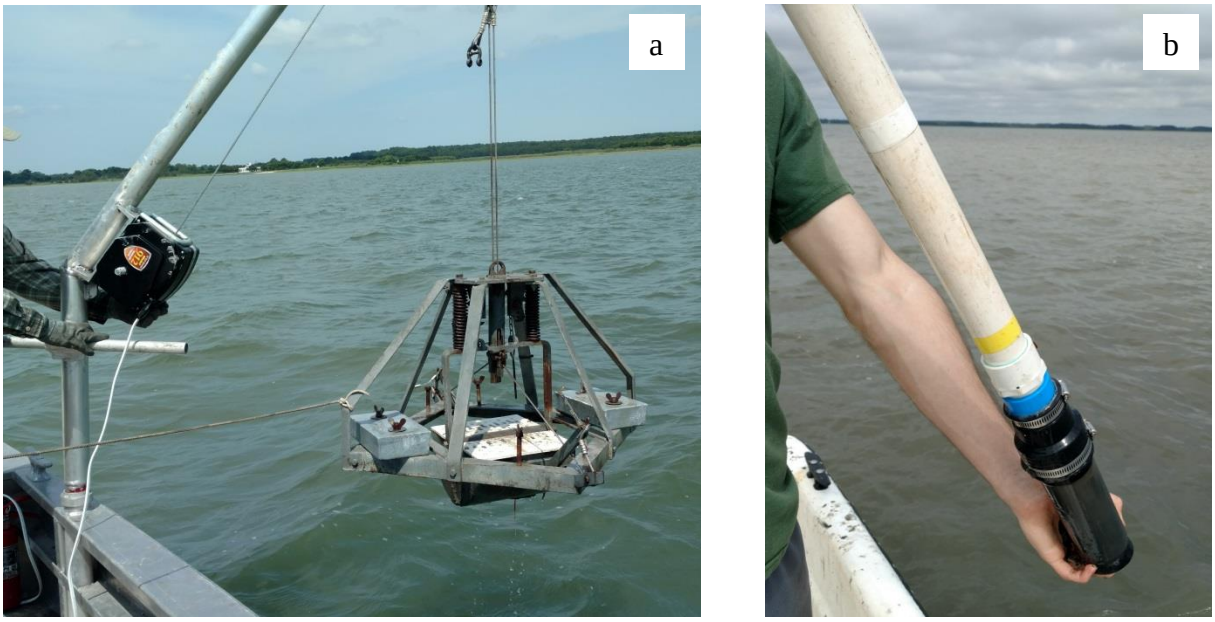

Fig. 5-1-1 Gear used to collect a) grab and b) push core samples. Subsamples from these were collected for surficial sediment organic matter and chlorophyll-a.

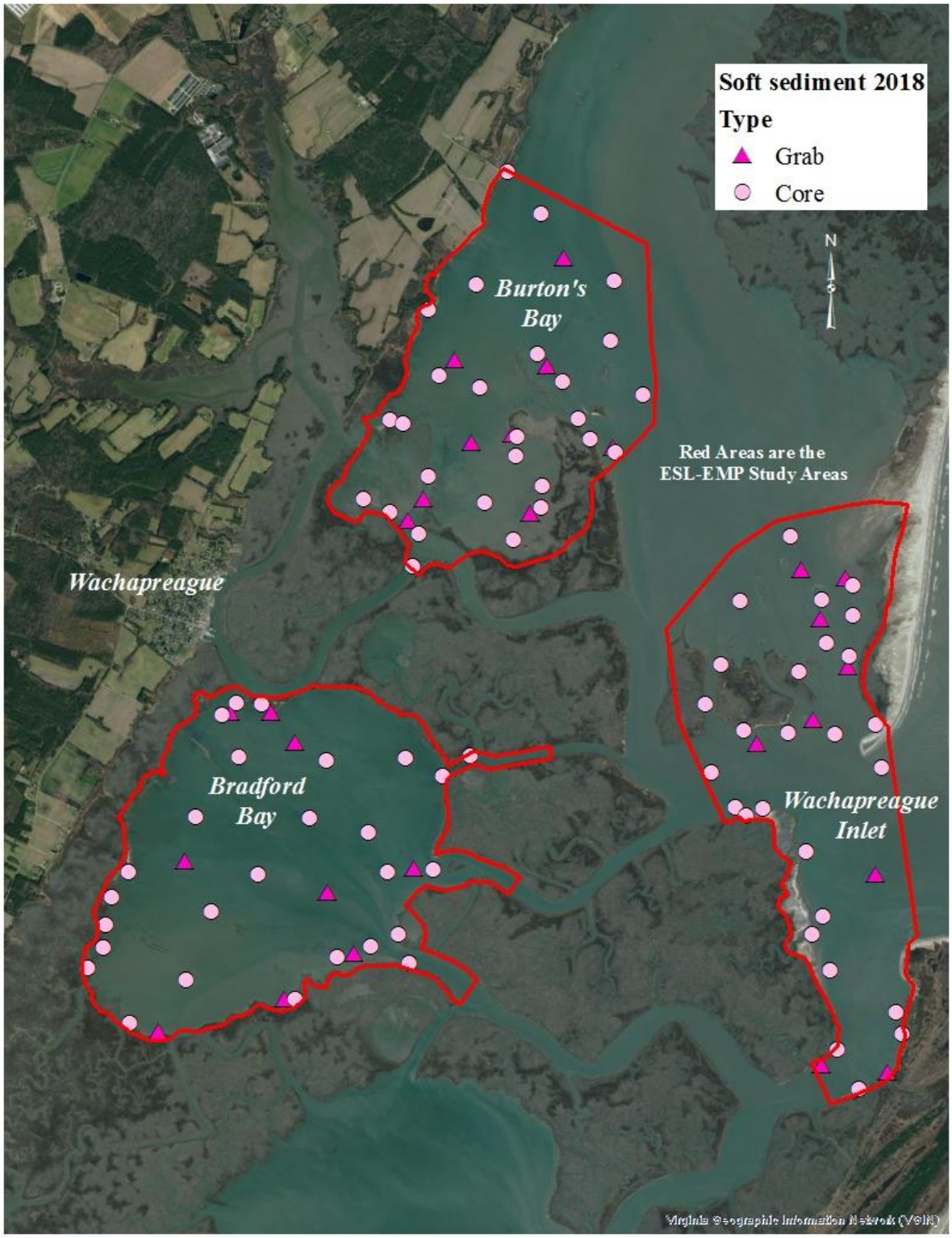

Fig. 5-1-2 Locations of 27 grab and 81 core sample sites where organisms were collected near Wachapreague, VA in 2018 (red polygons denote the ESL-EMP study areas).

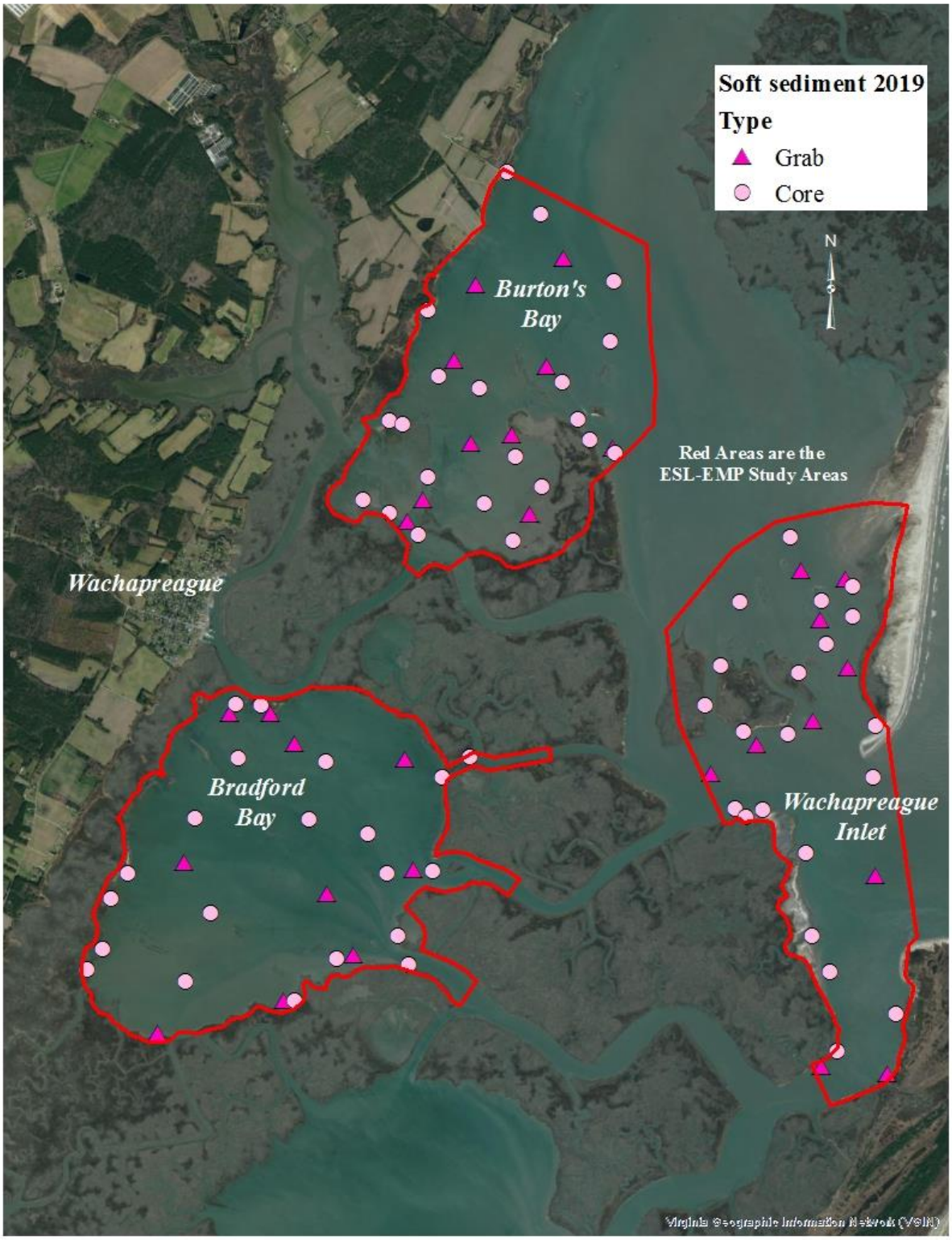

Fig. 5-1-3 Locations of 30 grab and 63 core sample sites where organisms were collected near Wachapreague, VA in 2019 (red polygons denote the ESL-EMP study areas).

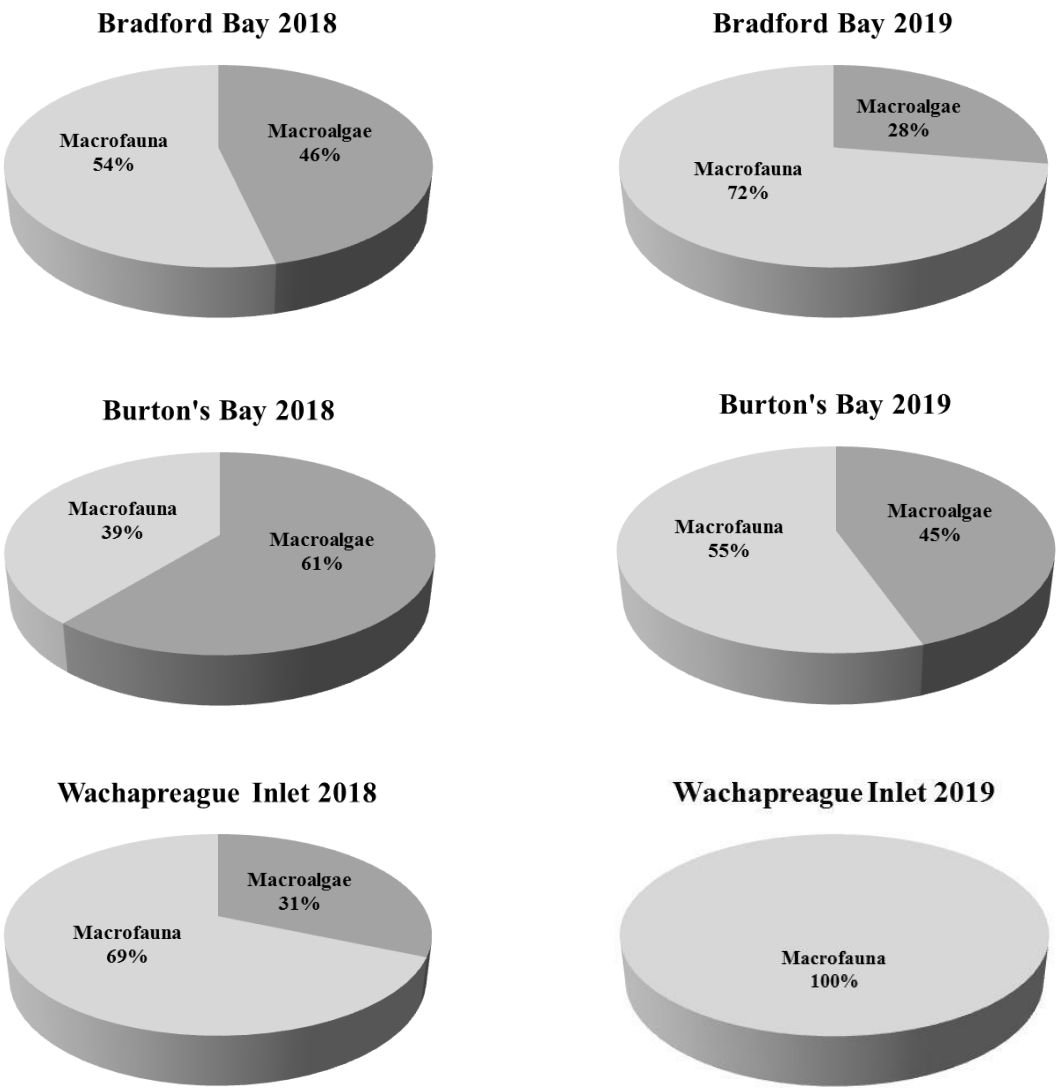

Fig. 5-1-4 Relative proportion (%) of the biomass (g/m^2) of macroalgae vs. macrofauna in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018 & 2019.

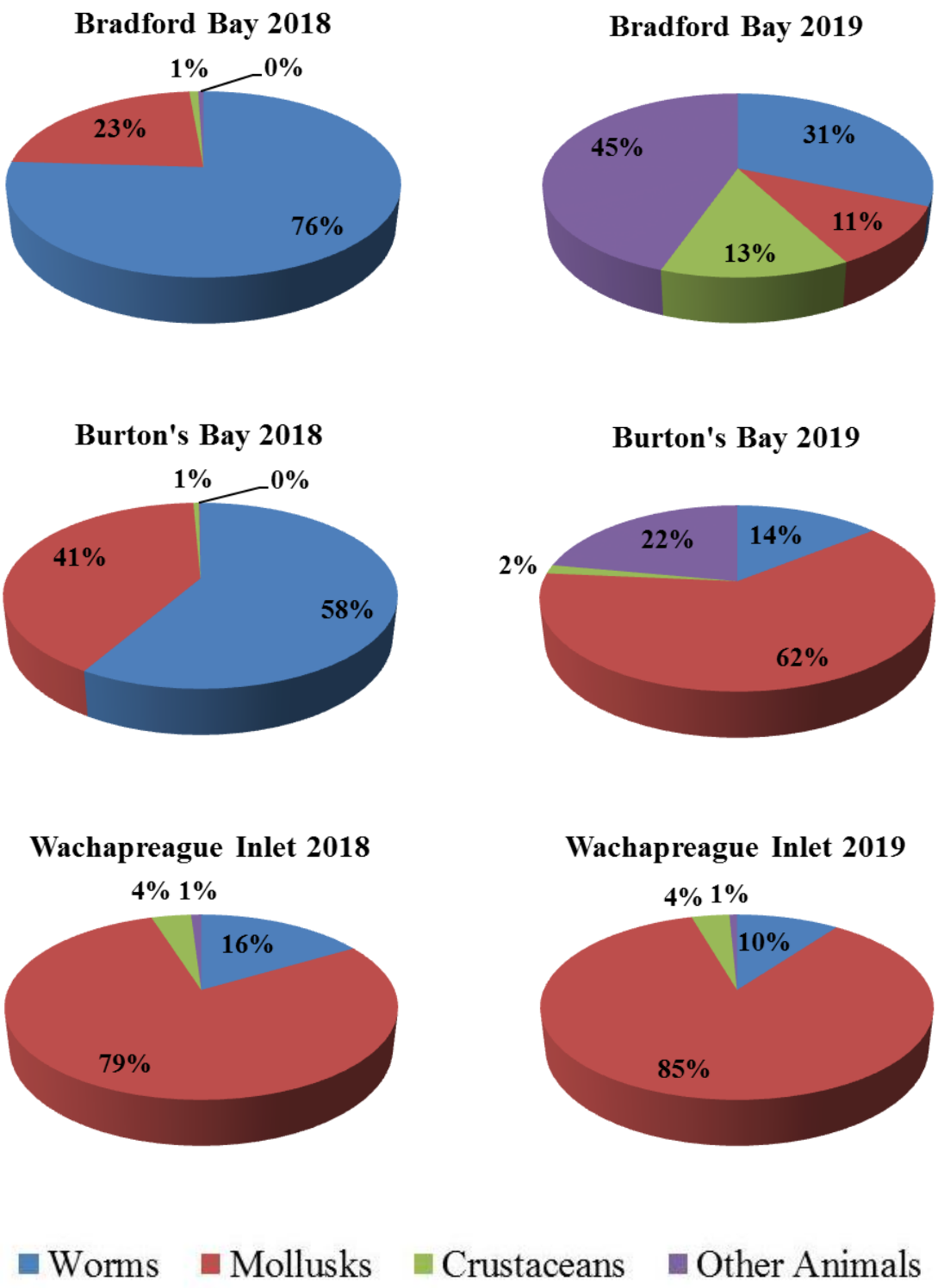

Fig. 5-1-5 Relative proportion (%) of the biomass (g/m^2) of macrofaunal taxa collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018 & 2019.

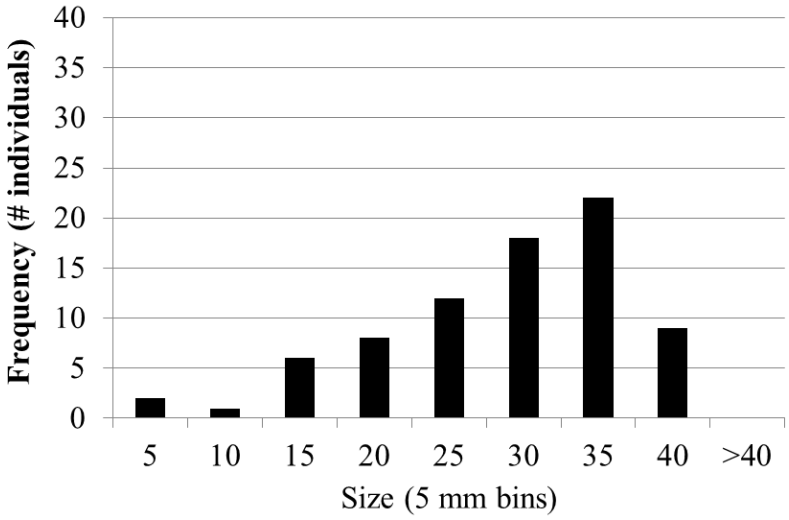

Fig. 5-1-5 Size frequency distribution (shell width, mm) of *Ensis leei* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2019.

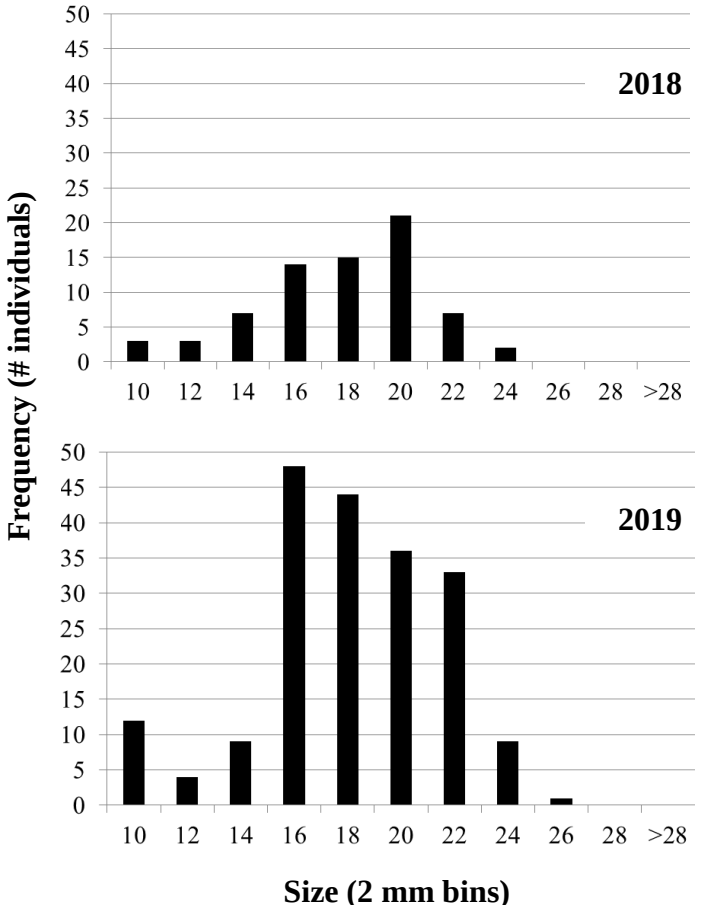

Fig. 5-1-6 Size frequency distribution (shell height, mm) of *Tritia obsoleta* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018 & 2019.

Chapter 5. Epi-benthic Community

Section 5-2: Hard Substrate Epi-benthic Community

Authors: PG Ross

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Complete	Planned	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 and one intertidal fringe reef within each of the three EMP geographical areas to monitor (9 reefs total; Fig. 5-2-1). These were reefs that appear to be representative of other sites throughout the area. At each reef, two haphazard quadrate 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 July/August of 2018 and late-May/early-June 2019. In future years, sampling will be conducted in the latter, earlier time frame for logistical practicalities and to avoid very early oyster settlement.

Additionally, we selected 2 subtidal shell beds in each geographic area (6 shell beds total; Fig. 5-2-1) and pulled a bottom dredge to collect shell substrate and associated organisms (Fig. 5-2-2). We could only sample 5 of these beds in 2019 due to extremely heavy macroalgae coverage at one of them; the dredge would clog with algae before shell could be collected. Length of dredge tows ranged from 21-68 m, depending on the size of the shell patch. Shell beds were sampled during early August 2018 and early June 2019.

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 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.

2018 & 2019 Results

Detailed results for the oyster (*Crassostrea virginica*) population were reported in Chapter 4-2. Additionally, 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 (quadrate samples) - In total, 1,102 and 1,426 individual organisms were sampled in 38 and 31 genera during 2018 and 2019, respectively. There was an increase in the relative proportion of macroalgae from 2018 to 2019 (Fig. 5-2-3). Overall, bivalves, gastropods, 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 2.27 and 2.13 in 2018 and 2019, respectively; ranging from 2.28 (2019) at the most dynamic Wachapreague Inlet site to 1.86 (2019) at 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). Individuals in the genus *Amphibalanus* <10 mm 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, 1,557 and 466 individual organisms were sampled during 2018 and 2019, respectively representing >58 and >54 genera, respectively. Once again, there was a large increase on the relative proportion of macroalgae from 2018 to 2019 (Fig. 5-2-6). While quite few less organisms were collected (note that this represents sampling on 6 reefs in 2018 and 5 in 2019; see above), over 3x the macroalgal biomass was collect in 2019 versus 2018. We suspect that the larger quantities of algae limited the gear efficiency of the dredge in 2019. Mollusks (mainly bivalves and snails), crustaceans (mainly amphipods), and sea squirts (ascidians; 2019 only) 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 2.91 and 2.00 in 2018 and 2019, respectively (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 apiculata* and *Diodora cayenensis* (Table 5-2-14).

Comparison to Previous Years

These were the first two formal years for the EMP. We do not have any previous comparable data for these specific sites or this area in general.

Discussion

The main objective for this portion of the EMP in 2018 and 2019 was to initially 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).

An example of metrics to track are the density and size distribution of ribbed mussels (*G. demissa*) and Xanthid mud crabs (mainly *Eurypanopeus depressus* and *Panopeus herbstii*) that define population dynamics and reflect integrated food web dynamics. Both of these groups can have impacts on the oyster population and, therefore, oyster reef habitats and their associated communities. Mussels can compete with oysters for space and food resources, whereas, mud crabs are known predators of juvenile oysters. The current size distribution of mud crabs shows a dramatic decline above 10 mm carapace width (see Fig. 5-2-5), likely due to predation of crabs by fish. However, if that distribution substantially changes over time, it could be a sign of an ecosystem change that may have far ranging impacts on oysters, since larger crabs can consume more and larger oysters.

Multiple years of data collection will be necessary to resolve patterns and trends from the background variation. For example, variation due to patchy distribution of habitats and species within them is significant. Also, the tendency for inverse relationships between organism size and abundance means higher variance for infrequently encountered larger organisms. Defining variance in population dynamics and repeated sampling is necessary to determine shifts in species ranges due to changing climate resulting in local invasion or local extinction.

2018 & 2019 Acknowledgements

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Table 5-2-1. Summary of the total density (# m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=18) on 9 intertidal oyster reefs near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*979.6*	*1,267.6*
Macroalgae			
Seaweeds	Macroalgae	+	+
Mollusks			
Clams	Bivalvia	169.8	144.9
Snails	Gastropoda (snails)	134.2	195.6
Slipper shells	Gastropoda (slipper shells)	0.9	
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	337.8	209.8
Amphipods	Amphipoda	150.2	540.4
Shrimp	Pleocyemata (Caridea)	2.7	
Isopods	Isopoda	4.4	8.9
Pea crabs	Brachyura (Pinnotheridae)	0.9	1.8
Barnacles	Balanidae	37.3	
Worms			
Polychaete worms	Polychaeta	111.1	159.1
Other Animals			
Anemones	Cnidaria (Actinaria)	23.1	4.4
Sponges	Porifera	+	
Bony Fish	Osteichthyes		0.9
Sea Squirts	Ascidiacea	0.9	0.9
Beetle Larvae	Coleoptera	6.2	0.9

Table 5-2-2. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=18) on 9 intertidal oyster reefs near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*44.4290*	*94.6129*
Macroalgae			
Seaweeds	Macroalgae	12.9368	47.9425
Mollusks			
Clams	Bivalvia	15.7373	34.5616
Snails	Gastropoda (snails)	1.5505	0.9816
Slipper shells	Gastropoda (slipper shells)	0.0017	
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	12.4136	8.1107
Amphipods	Amphipoda	0.0343	0.1881
Shrimp	Pleocyemata (Caridea)	0.0124	
Isopods	Isopoda	0.0008	0.0017
Pea crabs	Brachyura (Pinnotheridae)	0.0007	0.0278
Barnacles	Balanidae	0.0000	
Worms			
Polychaete worms	Polychaeta	1.5342	2.6836
Other Animals			
Anemones	Cnidaria (Actinaria)	0.1124	0.0198
Sponges	Porifera	0.0942	
Bony Fish	Osteichthyes		0.0928
Sea Squirts	Ascidiacea	<0.0001	0.0026
Beetle Larvae	Coleoptera	+	+

Table 5-2-3. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=18) on 9 intertidal oyster reefs near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Representative Taxonomic Grouping	Geographic Area	2018	2019
All Taxa Combined	*All 3 Areas*	*44.4290*	*94.6129*
All Taxa Combined	Bradford Bay	26.2203	56.8523
	Burton's Bay	16.2664	89.0476
	Wach. Inlet	90.8003	137.9388
Macroalgae (Seaweeds)	Bradford Bay	6.0053	0.1651
	Burton's Bay		32.1360
	Wach. Inlet	32.8051	111.5264
Mollusks (Snails, clams, etc.)	Bradford Bay	7.4525	39.6371
	Burton's Bay	9.2573	48.3225
	Wach. Inlet	35.1587	18.6703
Crustaceans (Crabs, shrimp, amphipods etc.)	Bradford Bay	11.1395	13.8648
	Burton's Bay	4.9235	6.3539
	Wach. Inlet	21.3227	4.7661
Worms	Bradford Bay	1.2755	3.1853
	Burton's Bay	1.9299	2.2352
	Wach. Inlet	1.3973	2.6304
Other Animals (Fish, echinoderms, anenomes etc.)	Bradford Bay	0.3475	
	Burton's Bay	0.1557	
	Wach. Inlet	0.1165	0.3456

Table 5-2-4. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=6) on 3 intertidal oyster reefs in the Bradford Bay study area near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*26.2203*	*56.8523*
Macroalgae			
Seaweeds	Macroalgae	6.0053	0.1651
Mollusks			
Clams	Bivalvia	2.8120	37.5208
Snails	Gastropoda (snails)	4.6355	2.1163
Slipper shells	Gastropoda (slipper shells)	0.0051	
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	11.0701	13.6053
Amphipods	Amphipoda	0.0320	0.2576
Shrimp	Pleocyemata (Caridea)	0.0373	
Isopods	Isopoda		0.0019
Pea crabs	Brachyura (Pinnotheridae)		
Barnacles	Balanidae	+	
Worms			
Polychaete worms	Polychaeta	1.2755	3.1853
Other Animals			
Anemones	Cnidaria (Actinaria)	0.0648	
Sponges	Porifera	0.2827	
Bony Fish	Osteichthyes		
Sea Squirts	Ascidiacea		
Beetle Larvae	Coleoptera		

Table 5-2-5. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=6) on 3 intertidal oyster reefs in the Burton's Bay study area near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*16.2664*	*89.0476*
Macroalgae			
Seaweeds	Macroalgae		32.1360
Mollusks			
Clams	Bivalvia	9.2477	48.1166
Snails	Gastropoda (snails)	0.0096	0.2059
Slipper shells	Gastropoda (slipper shells)		
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	4.9080	6.1293
Amphipods	Amphipoda	0.0131	0.2213
Shrimp	Pleocyemata (Caridea)		
Isopods	Isopoda	0.0024	0.0032
Pea crabs	Brachyura (Pinnotheridae)		
Barnacles	Balanidae		
Worms			
Polychaete worms	Polychaeta	1.9299	2.2352
Other Animals			
Anemones	Cnidaria (Actinaria)	0.1557	
Sponges	Porifera		
Bony Fish	Osteichthyes		
Sea Squirts	Ascidiacea	<0.0001	
Beetle Larvae	Coleoptera	<0.0001	

Table 5-2-6. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in quadrate samples (n=6) on 3 intertidal oyster reefs in the Wachapreague Inlet study area near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*90.8003*	*137.9388*
Macroalgae			
Seaweeds	Macroalgae	32.8051	111.5264
Mollusks			
Clams	Bivalvia	35.1523	18.0475
Snails	Gastropoda (snails)	0.0064	0.6228
Slipper shells	Gastropoda (slipper shells)		
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	21.2627	4.5973
Amphipods	Amphipoda	0.0579	0.0853
Shrimp	Pleocyemata (Caridea)		
Isopods	Isopoda		
Pea crabs	Brachyura (Pinnotheridae)	0.0021	0.0835
Barnacles	Balanidae	+	
Worms			
Polychaete worms	Polychaeta	1.3973	2.6304
Other Animals			
Anemones	Cnidaria (Actinaria)	0.1165	0.0595
Sponges	Porifera		
Bony Fish	Osteichthyes		0.2784
Sea Squirts	Ascidiacea		0.0077
Beetle Larvae	Coleoptera		<0.0001

Table 5-2-7. Summary of the total individual density (# m^{-2}) and biomass density (ash-free dry wt., g m^{-2}) of genera collected in intertidal oyster reef samples (quadrates; n=18) pooled for three study areas near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa and a blank cell indicates the absence of that taxon.

	# m^{-2}		g m^{-2}	
Taxon (~Genus)	**2018**	**2019**	**2018**	**2019**
All Taxa	*979.6*	*1,267.6*	*44.4290*	*94.6129*
Amphipoda	150.2	540.4	0.0343	0.1881
Ampelisca	1.8		0.0007	
Ampithoe	147.6	409.8	0.0336	0.1374
Corophium		3.6	0.0000	0.0012
Gammarus	0.9	10.7	<0.0001	0.0026
Melita		116.4		0.0468
Ascidiacea	0.9	0.9	<0.0001	0.0026
Molgula	0.9	0.9	<0.0001	0.0026
Balanidae	37.3		+	
Amphibalanus	37.3		+	
Bivalvia	169.8	144.9	15.7373	34.5616
Anadara	2.7		0.0021	
Anomia	21.3		0.0383	
Gemma	0.9		0.0004	
Geukensia	135.1	130.7	15.6451	30.2054
Limecola		0.9		0.0027
Mercenaria	8.0	11.6	0.0498	4.3516
Mulinia	0.9		0.0014	
Mytilus	0.9	1.8	0.0002	0.0020
Brachyura (Pinnotheridae)	0.9	1.8	0.0007	0.0278
Pinnixa	0.9	1.8	0.0007	0.0278
Cnidaria (Actinaria)	23.1	4.4	0.1124	0.0198
Diadumene	23.1	4.4	0.1124	0.0198
Coleoptera	6.2	0.9	+	+
Coleoptera	6.2	0.9	+	+
Gastropoda (slipper shells)	0.9		0.0017	
Crepidula	0.9		0.0017	
Gastropoda (snails)	134.2	195.6	1.5505	0.9816
Astyris		0.9		0.0005
Boonea	33.8	138.7	0.0050	0.1635
Costoanachis		0.9		<0.0001
Eupleura	1.8		0.0010	
Eupluera	0.9		0.0002	
Tritia	97.8	55.1	1.5444	0.8176

Table 5-2-7 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	**2019**	**2018**	**2019**
Isopoda	4.4	8.9	0.0008	0.0017
Cassidinidea	4.4	8.9	0.0008	0.0017
Macroalgae	+	+	12.9368	47.9425
Agardhiella	+		0.1365	
Enteromorpha		+		0.0241
Fucus	+	+	10.7835	39.6631
Gracilariopsis	+		1.7896	
Ulva	+	+	0.2272	8.2553
Osteichthyes		0.9		0.0928
Gobiosoma		0.9		0.0928
Pleocyemata (Caridea)	2.7		0.0124	
Alpheus	2.7		0.0124	
Pleocyemata (Xanthidae)	337.8	209.8	12.4136	8.1107
Dyspanopeus	3.6		0.0030	
Eurypanopeus	303.1	168.9	6.5506	4.2151
Panopeus	25.8	38.2	5.6677	3.8025
Unidentified Xanthidae	5.3	2.7	0.1923	0.0931
Polychaeta	111.1	159.1	1.5342	2.6836
Alitta	70.2	123.6	0.2031	1.2813
Arabella	0.9		0.0178	
Cirratulus	6.2	1.8	0.3794	0.0495
Cirriformia		3.6		0.3010
Clymenella		0.9		0.0016
Drilonereis	1.8	1.8	0.0016	0.0026
Glycera	0.9	0.9	0.0033	0.0040
Hypereteone	2.7		0.0185	
Lepidametria	0.9		0.0413	
Marphysa	27.6	24.9	0.8692	0.9945
Terebellidae		1.8		0.0201
Unidentified polychaete		+		0.0291
Porifera	+		0.0942	
Halichondria	+		0.0942	

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 reef samples (quadrates; n=18) pooled for three study areas near Wachapreague, VA during summer 2018-2019. This community data does not include oysters.

Community Metric	Geographic Area	2018	2019
Abundance (# m^{-2})	Bradford Bay	1,008	1,736
	Burton's Bay	893	1,259
	Wach. Inlet	1,037	808
	Overall	*980*	*1,268*
Taxa Richness	Bradford Bay	20	17
	Burton's Bay	20	16
	Wach. Inlet	24	25
	Overall	*38*	*31*
Shannon Diversity Index (H')	Bradford Bay	2.03	2.06
	Burton's Bay	1.90	1.86
	Wach. Inlet	2.08	2.28
	Overall	*2.27*	*2.13*

Table 5-2-9. Summary of sizes (mm using species-specific standard measurements) of species that were measured from samples collected in quadrate samples on intertidal oyster reefs near Wachapreague, VA during 2018-2019. 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			
	# < 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				
Bivalvia (non-Crassostrea)								
Geukensia demissa	30	122	10-106	37.1	16	123	10-86	38.7
Mercenaria mercenaria	4	1	11-11	11.0	3	4	47-70	56.8
Gastropoda (snails)								
Tritia obsoleta	23	8	11-22	16.0		13	11-24	15.7
Osteichthyes								
Gobiosoma bosc						1	45-45	45.0
Pleocyemata (Xanthidae)	284	73	10-34	13.3	149	86	10-33	11.5

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

Table 5-2-10. Summary of the total density (# m^{-2}; excludes oysters) of broad taxa collected in dredge samples (n=6 and n=5 in 2018 & 2019, respectively) on subtidal shell beds near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		***7.805***	***1.950***
Cnidarians			
Coral	Cnidaria (Scleractinia)	+	+
Anemones	Cnidaria (Actinaria)	0.160	0.226
Hydroids	Cnidaria (Hydrozoa)	+	+
Mollusks			
Clams/Oysters	Bivalvia	1.200	0.300
Limpets	Gastropoda (limpets)	0.110	0.038
Chitons	Polyplacophora	0.065	0.038
Snails	Gastropoda (snails)	0.271	0.247
Slipper shells	Gastropoda (slipper shells)	0.155	0.038
Nudibranchs	Gastropoda (nudibranchs)	0.351	
Macroalgae			
Seaweeds	Macroalgae	+	+
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	0.561	0.075
Hermit Crabs	Pleocyemata (Paguridae)	0.015	0.167
Shrimp	Pleocyemata (Caridea)	0.015	0.013
Amphipods	Amphipoda	2.647	0.699
Isopods	Isopoda	0.050	0.008
Worms			
Polychaete worms	Polychaeta	0.667	0.155
Ascidians			
Sea squirts	Ascidiacea	1.444	0.021
Other Animals			
Sea spiders	Pycnogonida (sea spider)	0.045	0.008
Bony Fish	Osteichthyes	0.055	
Bryozoans	Bryozoa	+	+

Table 5-2-11. Summary of the total biomass (ash-free dry wt., g m^{-2}; excludes oysters) of broad taxa collected in dredge samples (n=6 and n=5 in 2018 & 2019, respectively) on subtidal shell beds near Wachapreague, VA during summer 2018-2019. A "+" indicates presence of a taxa, typically those where weighing individuals is impractical, and a blank cell indicates the absence of that taxon.

Common Name	Representative Taxonomic Grouping	2018	2019
All Taxa		*0.1845*	*0.2382*
Cnidarians			
Coral	Cnidaria (Scleractinia)	0.0873	0.0089
Anemones	Cnidaria (Actinaria)	0.0009	0.0008
Hydroids	Cnidaria (Hydrozoa)	0.0004	0.0581
Mollusks			
Clams/Oysters	Bivalvia	0.0210	0.0314
Limpets	Gastropoda (limpets)	0.0124	0.0038
Chitons	Polyplacophora	0.0051	0.0029
Snails	Gastropoda (snails)	0.0046	0.0031
Slipper shells	Gastropoda (slipper shells)	0.0004	0.0005
Nudibranchs	Gastropoda (nudibranchs)	0.0002	
Macroalgae			
Seaweeds	Macroalgae	0.0361	0.1136
Crustaceans			
Mud Crabs	Pleocyemata (Xanthidae)	0.0076	0.0033
Hermit Crabs	Pleocyemata (Paguridae)	0.0020	0.0085
Shrimp	Pleocyemata (Caridea)	0.0005	0.0001
Amphipods	Amphipoda	0.0004	0.0002
Isopods	Isopoda	0.0001	<0.0001
Worms			
Polychaete worms	Polychaeta	0.0024	0.0013
Ascidians			
Sea squirts	Ascidiacea	0.0019	0.0012
Other Animals			
Sea spiders	Pycnogonida (sea spider)	<0.0001	<0.0001
Bony Fish	Osteichthyes	0.0008	
Bryozoans	Bryozoa	0.0004	0.0007

Table 5-2-12. Summary of the density (# m^{-2}) and total biomass (ash-free dry wt., g m^{-2}) of genera collected in dredge samples (n=6 and n=5 in 2018 & 2019, respectively) on subtidal shell beds near Wachapreague, VA during summer 2018-2019. 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**	**2018**	**2019**
All Taxa	*7.805*	*1.950*	*0.1845*	*0.2382*
Amphipoda	2.647	0.699	0.0004	0.0002
Ampelisca	0.055	0.071	<0.0001	<0.0001
Ampithoe	0.201	0.071	0.0001	<0.0001
Batea		0.004		<0.0001
Caprella	0.070	0.059	<0.0001	<0.0001
Corophium	1.048	0.050	0.0001	<0.0001
Gammarus	0.737	0.326	0.0002	0.0001
Lysianopsis		0.021		<0.0001
Melita		0.042		<0.0001
Paracaprella	0.481	0.054	<0.0001	<0.0001
Trichophoxus	0.055		<0.0001	
Ascidiacea	1.444	0.021	0.0019	0.0012
Ecteinascidia	1.429		0.0019	
Molgula	0.015	0.008	<0.0001	0.0006
Styela		0.013		0.0006
Bivalvia (Crassostrea)	0.040	0.025	0.0052	0.0067
Crassostrea	0.040	0.025	0.0052	0.0067
Bivalvia	1.143	0.188	0.0158	0.0247
Anadara	0.707	0.042	0.0001	0.0017
Anomia	0.356	0.138	0.0147	0.0230
Barnea	0.005		0.0001	
Lunarca	0.005		0.0006	
Mercenaria	0.010		<0.0001	
Mulinia	0.005	0.008	<0.0001	<0.0001
Mya	0.020		<0.0001	
Noetia	0.020		0.0003	
Petricolaria	0.005		<0.0001	
Tagelus	0.010		<0.0001	
Bryozoa	+	+	0.0004	0.0007
Bugula	+	+	0.0004	0.0007
Cnidaria (Actinaria)	0.160	0.226	0.0009	0.0008
Diadumene	0.140	0.226	0.0008	0.0008
Exaiptasia	0.015		<0.0001	
Unknown sea anenome	0.005		<0.0001	

Table 5-2-12 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	2019	2018	2019
Cnidaria (Hydrozoa)	+	+	0.0004	0.0581
Bougainvillia		+		0.0070
Unknown hydroid	+	+	0.0004	0.0510
Cnidaria (Scleractinia)	+	+	0.0873	0.0089
Astrangia	+	+	0.0873	0.0089
Gastropoda (limpets)	0.110	0.038	0.0124	0.0038
Diodora	0.110	0.038	0.0124	0.0038
Gastropoda (nudibranchs)	0.351		0.0002	
Cariopsilla	0.261		0.0001	
Corambe	0.090		<0.0001	
Gastropoda (slipper shells)	0.155	0.038	0.0004	0.0005
Crepidula	0.155	0.038	0.0004	0.0005
Gastropoda (snails)	0.271	0.247	0.0046	0.0031
Acteocina	0.010		<0.0001	
Astyris	0.145	0.008	0.0001	<0.0001
Boonea		0.004		<0.0001
Busycon	0.005		<0.0001	
Costoanachis		0.213		0.0027
Nucella		0.004		0.0001
Phrontis	0.040		0.0041	
Seila	0.065	0.008	0.0002	<0.0001
Tritia	0.005	0.008	0.0001	0.0003
Isopoda	0.050	0.008	0.0001	0.0000
Cyathura	0.005		<0.0001	
Edotea	0.010	0.008	<0.0001	<0.0001
Erichsonella	0.030		0.0001	
Synidotea	0.005		0.0001	
Macroalgae	+	+	0.0361	0.1136
Ceramium		+		0.0019
Codium		+		0.0180
Ectocarpus		+		0.0003
Fucus	+		0.0081	
Gracilariopsis	+	+	0.0173	0.0627
Porphyra		+		0.0004
Ulva	+	+	0.0107	0.0304
Malacostraca (Mysida)	0.010		<0.0001	
Unknown Mysid	0.010		<0.0001	

Table 5-2-12 (continued)

Taxon (~Genus)	# m^{-2}		g m^{-2}	
	2018	2019	2018	2019
Osteichthyes	0.055		0.0008	
Gobiosoma	0.055		0.0008	
Ostracoda (Myodocopida)		0.004		<0.0001
Cylindroleberis		0.004		<0.0001
Pleocyemata (Caridea)	0.015	0.013	0.0005	0.0001
Alpheus	0.005		0.0005	
Crangon	0.005		<0.0001	
Ogyrides		0.013		0.0001
Palaemon	0.005		<0.0001	
Paguridae	0.015	0.167	0.0020	0.0085
Pagurus	0.015	0.167	0.0020	0.0085
Pleocyemata (Xanthidae)	0.561	0.075	0.0076	0.0033
Dyspanopeus		0.054		0.0028
Eurypanopeus	0.416	0.008	0.0017	0.0002
Panopeus	0.145	0.013	0.0058	0.0003
Polychaeta	0.667	0.155	0.0024	0.0013
Alitta	0.050	0.008	<0.0001	0.0001
Amphitrite		0.004		<0.0001
Arabella		0.004		<0.0001
Diopatra		0.004		0.0005
Drilonereis	0.020	0.025	<0.0001	<0.0001
Lepidonotus	0.331	0.038	0.0004	0.0001
Lumbrineris		0.004		<0.0001
Marphysa	0.251	0.046	0.0020	0.0004
Ninoe		0.013		<0.0001
Pectinaria		0.004		<0.0001
Sabellaria	0.010	0.004	<0.0001	<0.0001
Spiochaetopterus	0.005		<0.0001	
Unknown polychaete	+	+	<0.0001	0.0001
Polyplacophora	0.065	0.038	0.0051	0.0029
Chaetopleura	0.065	0.038	0.0051	0.0029
Pycnogonida (sea spider)	0.045	0.008	<0.0001	<0.0001
Achelia	0.045	0.004	<0.0001	<0.0001
Callipallene		0.004		<0.0001

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 (n=6 and n=5 in 2018 & 2019, respectively) on subtidal shell beds near Wachapreague, VA during summer 2018-2019.

Community Metric	2018	2019
Abundance (# m^{-2})	7.8	1.9
Taxa Richness	58	54
Shannon Diversity Index (H')	2.91	2.00

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.

	#	Range (mm)	Avg (mm)
Bivalvia (non-Crassostrea)			
Anomia simplex	33	25-43	35.5
Polyplacophora			
Chaetopleura apiculata	9	6-25	17.7
Gastropoda (limpets)			
Diodora cayenensis	9	6-30	17.4

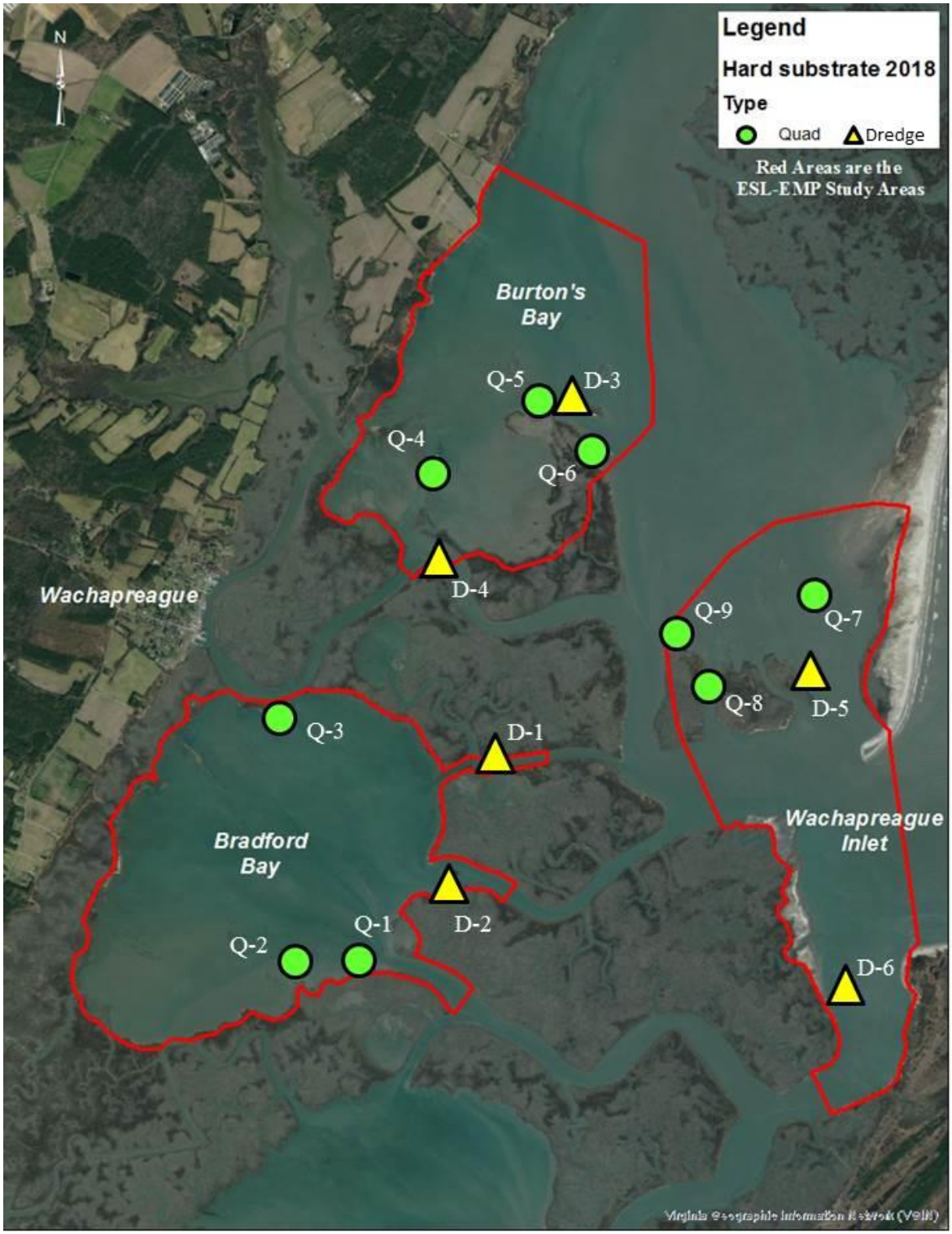

Fig. 5-2-1 Locations of 9 intertidal oyster reefs (green circles) and 6 subtidal shell beds (yellow triangles) monitoring sites near Wachapreague, VA for 2018 & 2019 (red polygons denote the ESL-EMP study areas).

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

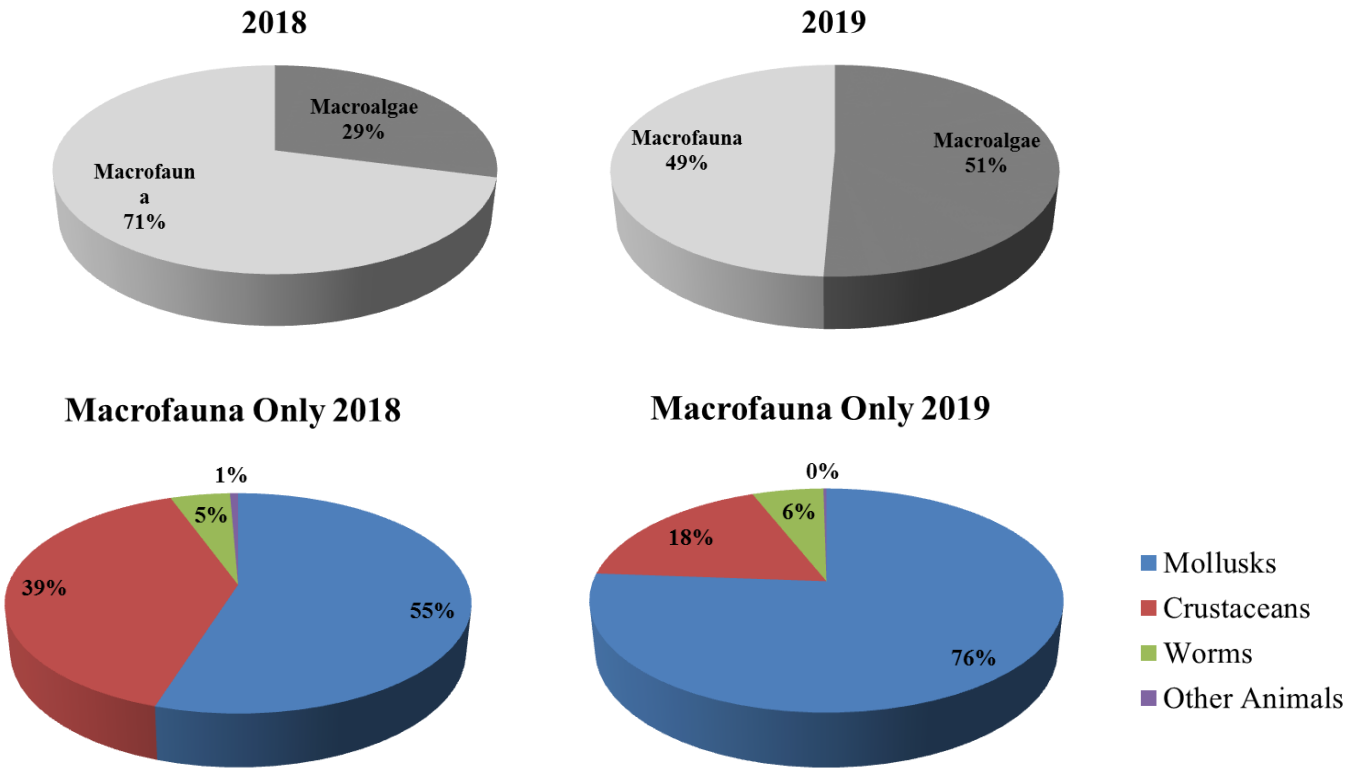

Fig. 5-2-3 Relative proportion (%) of the biomass (g/m^2) of various non-oyster taxa collected in intertidal oyster reef samples near Wachapreague, VA during summer 2018-2019.

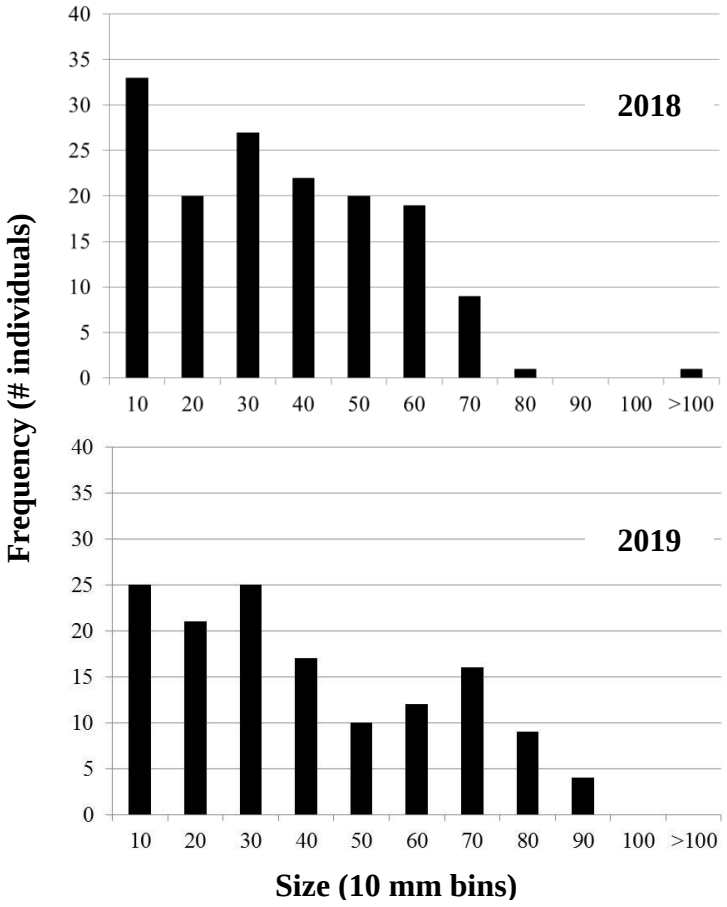

Fig. 5-2-4 Size frequency distribution (shell height, mm) of *Geukinsia demissa* collected in quadrate samples on intertidal oyster reefs in 3 regions near Wachapreague, VA during summer 2018 & 2019

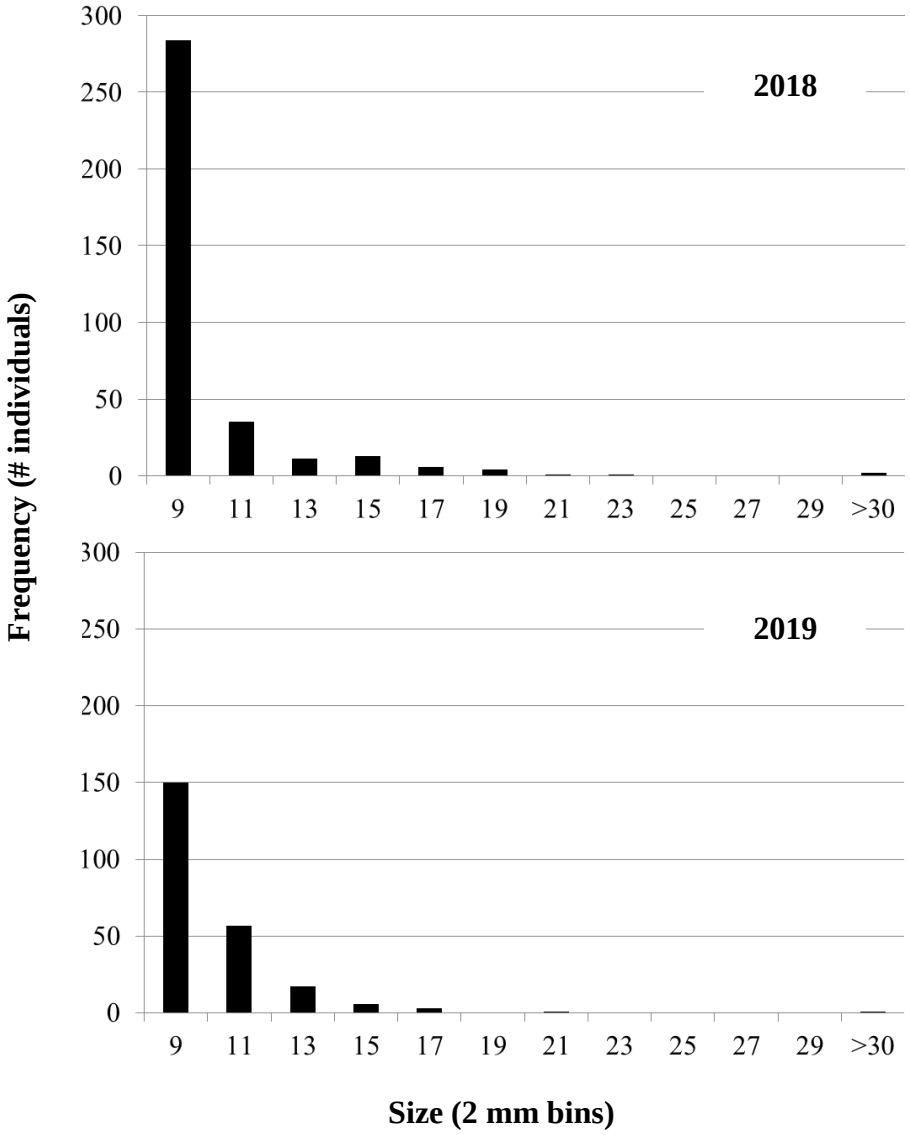

Fig. 5-2-5 Size frequency distribution (carapace width, mm) of mud crabs (*Xanthidae*) collected in quadrate samples on intertidal oyster reefs in 3 regions near Wachapreague, VA during summer 2018 & 2019.

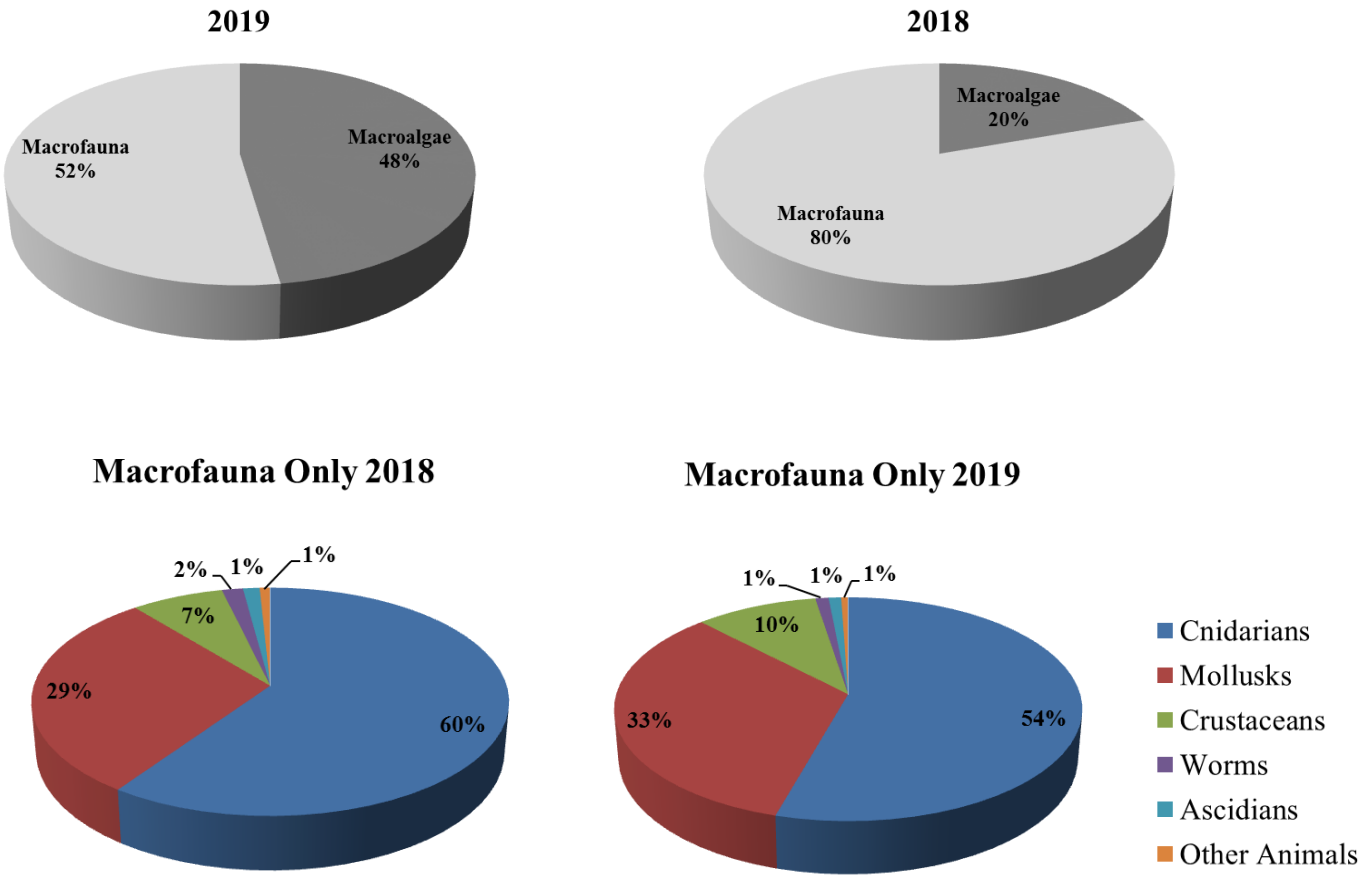

Fig. 5-2-6 Relative proportion (%) of the biomass (g/m^2) of various taxa collected in subtidal shell bed samples near Wachapreague, VA during summer 2018-2019.

Chapter 6. Mapping Coastal Change

Section 6-1: Wachaprague Inlet Vicinity Shoreline Mapping

Authors: PG Ross & Richard Snyder

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete	Partial	Planned		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 manifests across 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 fairly stable historically, 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 this on 5 to 7 year intervals and the changes to Cedar Island, and the other inlet areas in recent years, have been significant. Given the recent rapid changes, we plan to document bi-annual shoreline movement in the interim periods between VBMP image collection years (the next VBMP imaging effort for this region should be around 2021-2022) and at finer scale than available from satellite remote sensing.

Study Area & Methods

We document changes of the shoreline that generally defines Wachapreague Inlet, but also include nearby back marsh areas. For 2018, we focused on the southern portion of Cedar Island; east portion of Clubhouse Marsh; and the marsh islands in the vicinity of the Wye and Thorofare channels, including Sandy Point (Fig. 6-1-1).

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 2018 data. Background information for VBMP data can be accessed online (https://www.vita.virginia.gov/integrated-services/vgin-geospatial-services/orthoimagery/). We plan to incorporate other aerial image data from intervening years at a later date. 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, 2018). We manually digitized approximate neap high tide shoreline edges. This workflow creates shoreline maps with approximately 1-2 m accuracy. This is acceptable for our mapping objectives at this point since we are mainly interested in relative gross and substantial shoreline changes over time. We did not utilize ground control points in 2018, but plan to do so in future surveys.

2018 Results

Drone surveys collected 917 images (120 m altitude; 70% overlap) that were stitched together and developed into high resolution, georeferenced orthomosaics using the Precision Mapper cloud-based application. This resulted in a survey of ~190 hectares of island/marsh which encompassed about 16,600 m of shoreline (Fig. 6-1-3).

Comparison to Previous Years

The results for 2018 provide a visualization of shoreline changes from 2009-2017 and from 2017-2018 (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 2018, 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 nearly double it's 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). Aside from the major changes of Cedar Island, shoreline combined loss during the entire 2009-2018 period ranged from 13.3 to 0.0 m yr^{-1} with only one sentinel site having minor accretion (Table 6-1-2). When the two time periods are organized separately (i.e. ~Mar 2009-Mar 2017 vs. Mar 2017-Sep 2018), 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 relationship to distance from the geometric center of the 2018 inlet (Fig. 6-1-7). We quantified that for the Clubhouse marsh area since it is directly facing the inlet proper and receiving significant wave energy from the expanded inlet (Fig 6-1-8) which shows a strong quantitative relationship between shoreline loss and distance to inlet center for this area.

Discussion

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 will make it impossible to tell whether rates of change are remaining constant, increasing or slowing down without long term data. These data will be available to researchers for incorporation into geomorphological analyses providing context and value added to grant funding for such work.

2018 Acknowledgements

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

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Raff, J.L., Shawler, J.L., Ciarletta, D.J., Hein, E.A., Lorenzo-Trueba, J., Hein, C.J., 2018, Insights into barrier-island stability derived from transgressive/regressive state changes of Parramore Island, Virginia, *Marine Geology*, v. 403, p. 1-19, doi:10.1016/j.margeo.2018.04.007.

Shawler, J.L., Ciarletta, D.J., Lorenzo-Trueba, J., Hein, C.J., 2019. Drowned foredune ridges as evidence of pre-historical barrier-island state changes between migration and progradation, In: *Coastal Sediments '19*, p. 158-171, doi: 10.1142/9789811204487_0015

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

Table 6-1-2. Shoreline loss (red) and gain (blue) of at least +/- 2 m at 30 sentinel points from 2009-2018 near Wachapreague Inlet (+ indicates net loss and – indicates net accretion). Inlet point refers to distance from the specific sentinel point to the geometric center of the 2018 inlet (see Fig. 6-1-7).

Region	ID	Distance (m)	Rate (m yr^{-1})	Inlet Point (m)
Cedar Island	1	186.9	19.5	1,649
	2	400.5	41.7	1,066
	3	1,290.7	134.4	797
	4	-219.8	-22.9	1,084
	5	6.1	0.6	1,365
	6	4.3	0.4	1,643
Clubhouse Marsh	7	4.7	0.5	2,051
	8	10.2	1.1	1,704
	9	14.4	1.5	1,273
	10	64.6	6.7	885
	11	127.5	13.3	913
	12	64.1	6.7	1,008
	13	7.9	0.8	1,367
	14	7.3	0.8	1,561
Wye Marsh	15	7.5	0.8	1,872
	16	17.1	1.8	1,783
	17	4.6	0.5	1,855
Thorofare E Island	18	7.3	0.8	1,866
	19	28.1	2.9	1,512
	20	0.0	0.0	1,720
	21	1.1	0.1	1,985
Thorofare Mid Island	22	4.1	0.4	1,845
	23	20.1	2.1	1,492
	24	4.2	0.4	1,836
	25	-1.3	-0.1	2,089
Thorofare W Island	26	5.4	0.6	2,229
	27	11.8	1.2	2,005
	28	15.4	1.6	2,123
	29	5.6	0.6	2,342
	30	6.5	0.7	2,616

Table 6-1-3. Rate of shoreline loss (red) and gain (blue) of at least +/- 1.0 m/yr at 30 sentinel points by time period (+ indicates loss and – indicates accretion).

Region	ID	~Mar 2009-Mar 2017 Rate (m yr^{-1})	Mar 2017-Sep 2018 Rate (m yr^{-1})
Cedar Island	1	16.2	35.8
	2	59.2	-45.6
	3	182.3	-104.6
	4	-27.9	2.3
	5	0.8	0.0
	6	0.5	0.0
Clubhouse Marsh	7	0.3	1.4
	8	1.1	0.8
	9	1.8	0.0
	10	6.9	5.8
	11	14.5	7.0
	12	7.4	3.3
	13	1.0	0.0
	14	0.9	0.0
Wye Marsh	15	0.7	1.1
	16	1.7	2.3
	17	0.6	0.0
Thorofare E Island	18	0.7	1.3
	19	2.9	3.3
	20	0.1	-0.5
	21	0.1	0.0
Thorofare Mid Island	22	0.5	0.3
	23	1.8	3.4
	24	0.5	0.2
	25	-0.3	0.6
Thorofare W Island	26	0.5	1.1
	27	1.1	2.1
	28	1.4	2.6
	29	0.5	1.1
	30	0.6	1.3

Fig. 6-1-1 Area of 2018 shoreline change mapping effort in the vicinity of Wachapreague Inlet (highlighted in yellow).

Fig. 6-1-2 Drone collecting aerial images during 2018 near Wachapreague, VA.

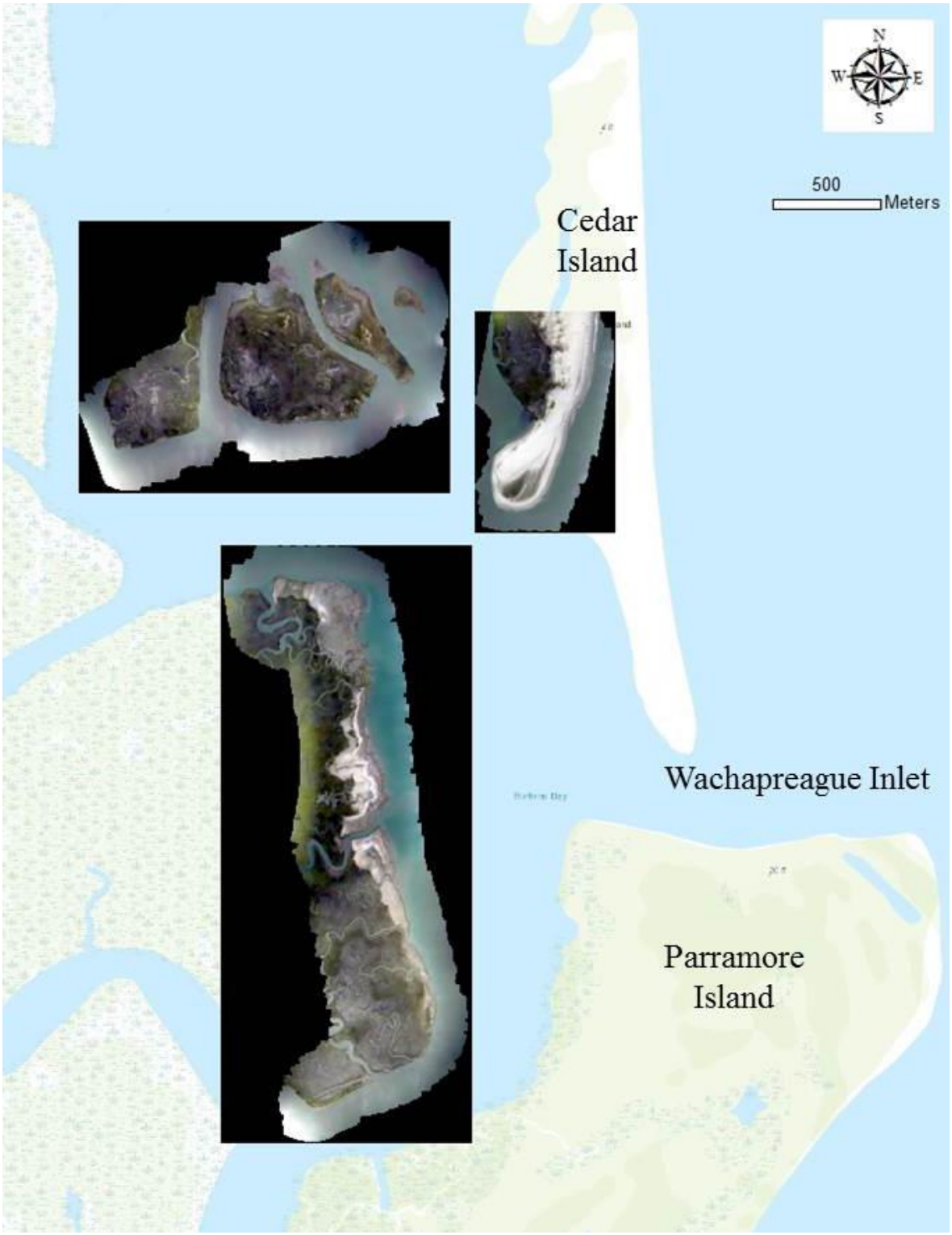

Fig. 6-1-3 Three orthomosaics derived from drone images collected in 2018 in the vicinity of Wachapreague inlet, VA (overlaid on basic base map).

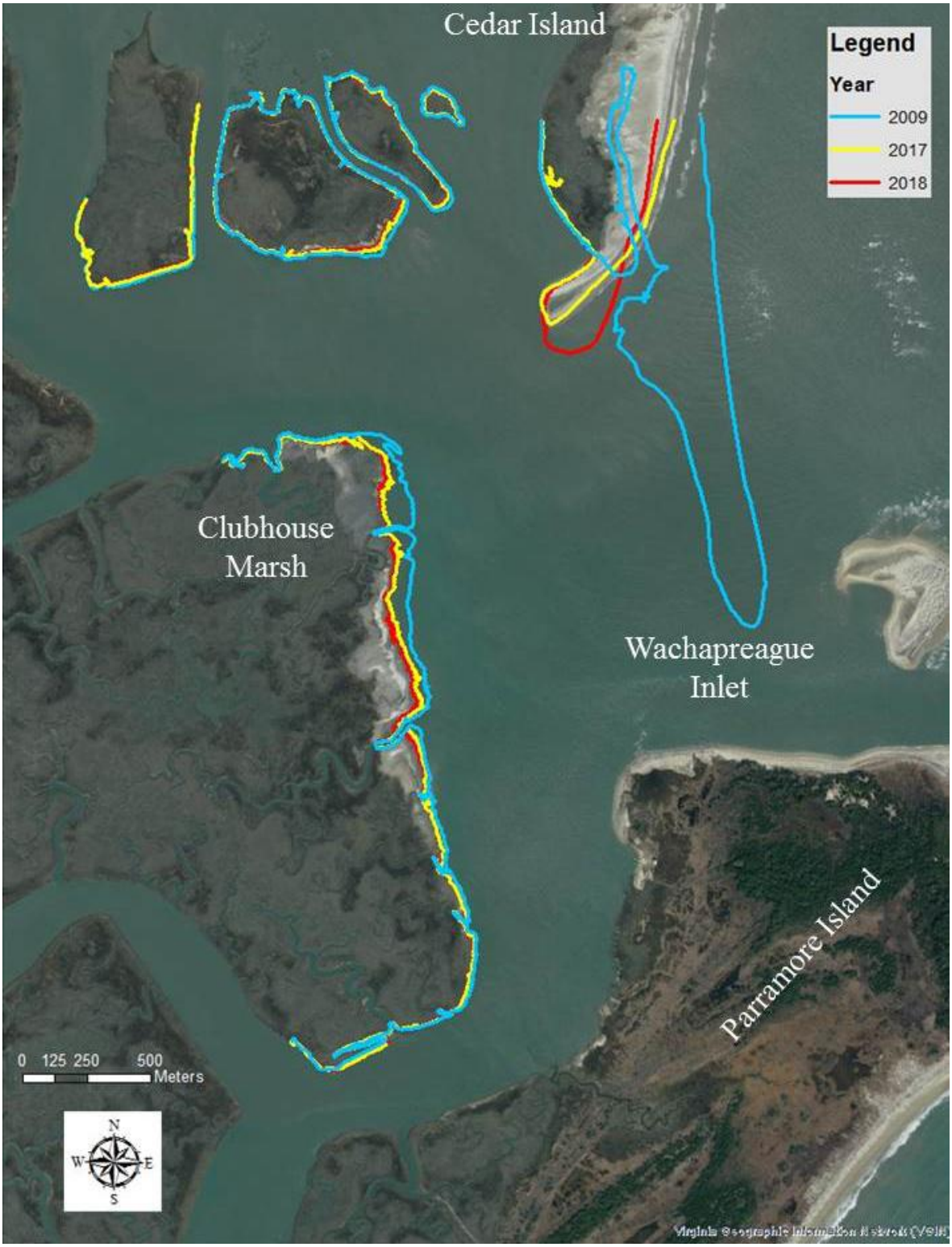

Fig. 6-1-4 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2018 (red) in the vicinity of Wachapreague Inlet, VA. Aerial background for this figure is 2017 imagery (VBMP).

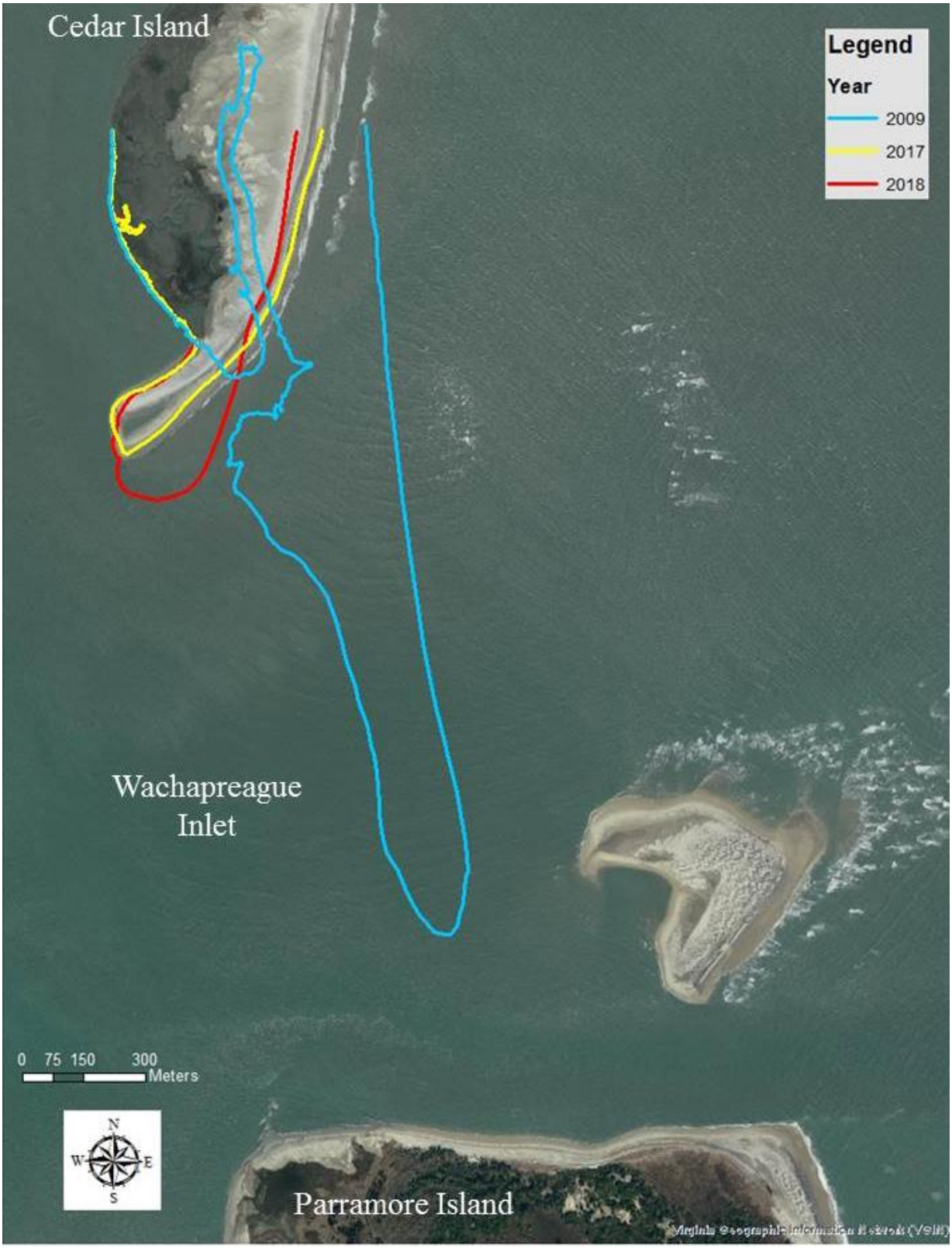

Fig. 6-1-5 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2018 (red) for the southern portion of Cedar Island. Aerial background for this figure is 2017 imagery (VBMP).

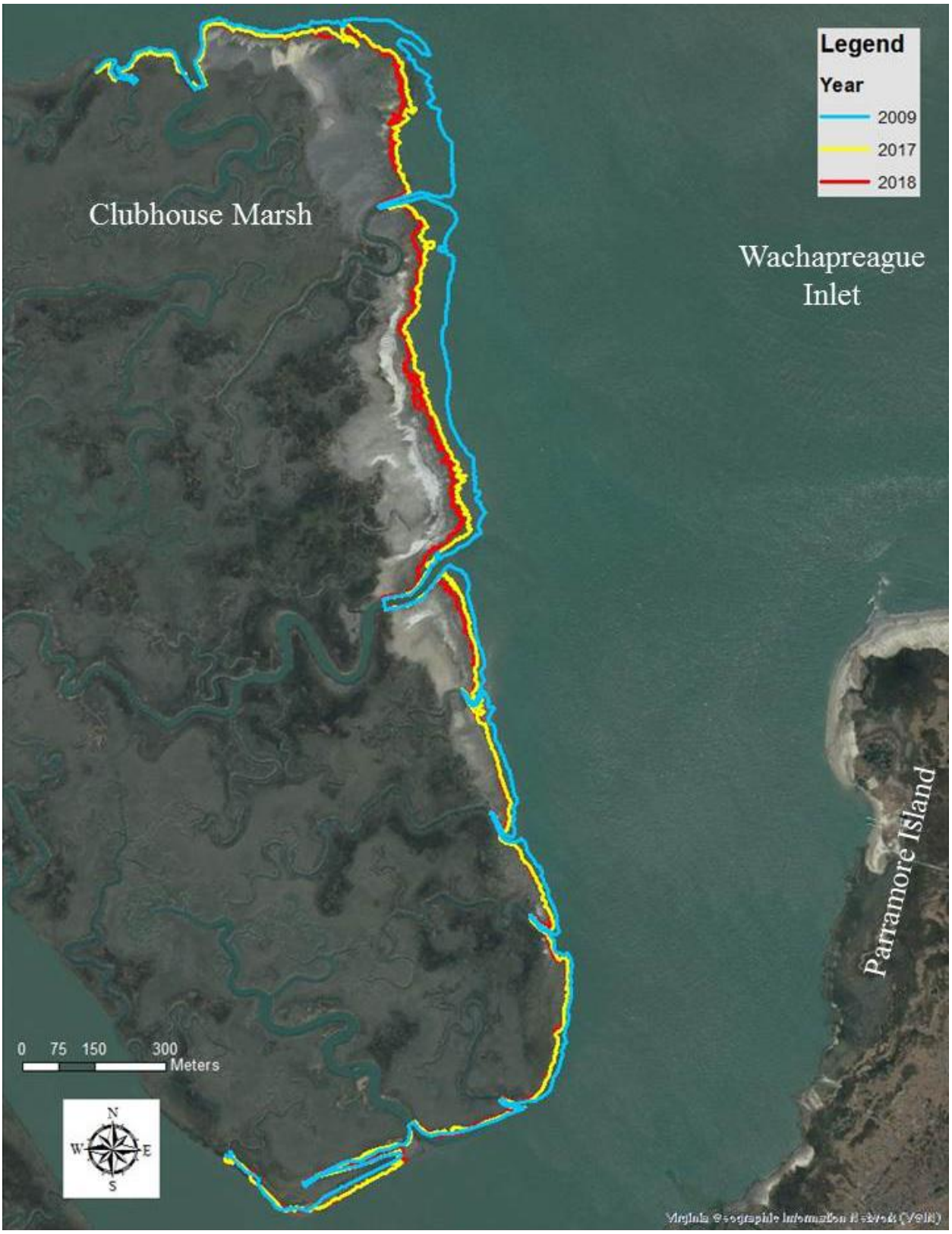

Fig. 6-1-6 Digitized shoreline from 2009 (blue), 2017 (yellow) and 2018 (red) in the vicinity of Clubhouse Marsh. Aerial background for this figure is 2017 imagery (VBMP).

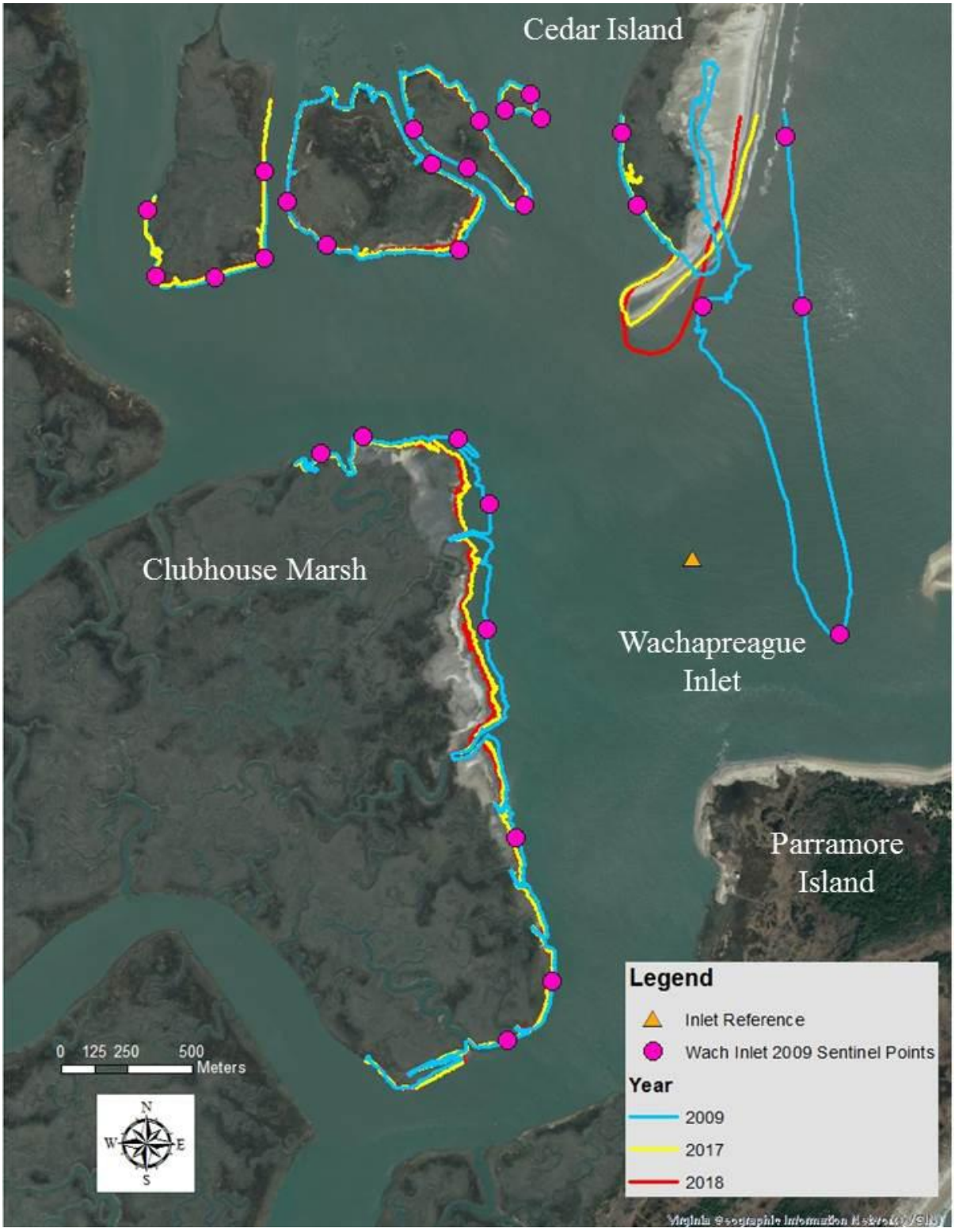

Fig. 6-1-7 Representative sentinel points to estimate shoreline retreat over time (pink dots) and a representative geometric center for the inlet (orange triangle).

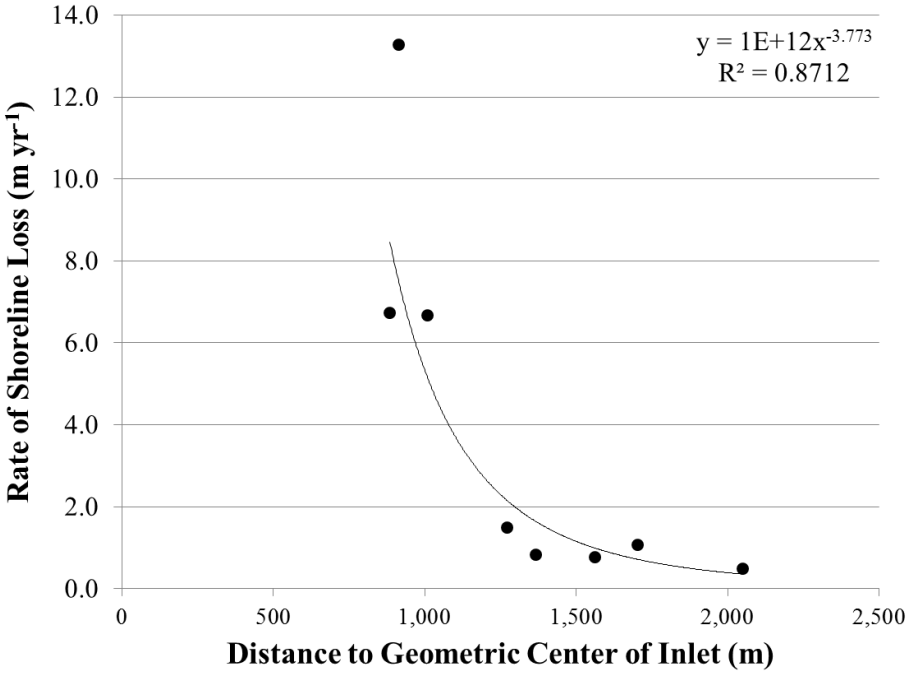

Fig. 6-1-8 Relationship between 2009-2018 shoreline loss (m yr^{-1}) and distance (m) to the geometric center of Wachapreague Inlet for 8 sentinel sites along the Clubhouse Marsh vicinity (best-fit power function with resulting model and R^2).

Chapter 6. Mapping Coastal Change

Section 6-2: Marsh Dieback Mapping

Authors: P.G. Ross and Richard Snyder

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

5-year sampling plan:

2018	*2019*	*2020*	*2021*	*2022*
Complete		Underway		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 around 2011, areas of marsh dieback were observed in Nickawampus and Finney Creek, north of the Eastern Shore Laboratory, and these areas have expanded (Gutsell, 2016). Once prolific Spartina marshes have converted to mudflats with micro and macro algae production. Several researchers have made preliminary investigations without significant results, including transplants of *Sporobolus alterniflorus* (Luckenbach & Perry, pers. comm.), plants and organisms from die back areas into healthy marsh (Ross & Snyder, unpublished), and a graduate student who studied environmental variables that might affect *Sporopbolus alterniflorus* 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

We focused on one drain or 'gut' in the marsh just north of Wachapreague on Finney Creek (Fig. 6-2-1). Initially, 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/). We plan to incorporate other aerial image data from intervening years at a later date.

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.

Georeferenced images from both sources were brought into ArcGIS (ESRI, 2018). 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 near-infrared images 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. (Fig. 6-2-3). Resolution with this technique was approximately 24 cm/pixel (original 2.4 cm/pixel was re-sampled based on 10 nearest neighbors).

2018 Results

The 2018 drone survey collected 331 images (60 m altitude; 70% overlap) on May 22 that were stitched together and developed into a high resolution, georeferenced orthomosaic using the Precision Mapper cloud-based application. This resulted in a survey of ~30 hectares of marsh/mud flat, of which ~12 hectares were contained in the actual study area. While we are most interested in documenting specific habitat types for 2018 using the NDVI as a standardized technique, we plan to compare previous years in a more rigorous way to determine temporal change moving forward.

Based on supervised NDVI analysis, we estimate that 73,000 m^2 (7.3 hectares) or 62% 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 (Ross, personal observation).

Comparison to Previous Years

We compared data from 2018 to the map developed in 2014 (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 are appropriate. The marsh die back area in 2014 was estimated to be 2.7 hectares or 23% of the delineated study area. This has nearly tripled by

2018. Even by these gross comparisons, it is clear that the die off has substantially expanded during this 4-year period.

Discussion

The marsh changes in the vicinity of Wachapreague are visually obvious and it appears that our recent data support this. This marsh die back appears to be an ongoing event. The structural and process dynamics of the change from Spartina production to micro and macroalgae production have not been explored. This dramatic shift in ecosystem function will undoubtedly affect food web dynamics and overall diversity and production in the system. We plan to provide a more in-depth comparison of past data during the 2020 sampling effort to determine rates of change within the study area.

Acknowledgements

We would like to thank Edward Smith, Sean Fate 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

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

Habitat ID	Habitat Name	Area (hectares)	% of Study Area
1	Water	0.63	5.4
2	Mud*	2.09	17.9
3	Microbial Mat (Mud)*	5.22	44.7
4	Sparse Grass/Thick Microbial Mat	2.29	19.6
5	Thick Grass/Shrubs or Trees	1.46	12.5

***** *These two categories can be generally thought of as the die-off area*

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.

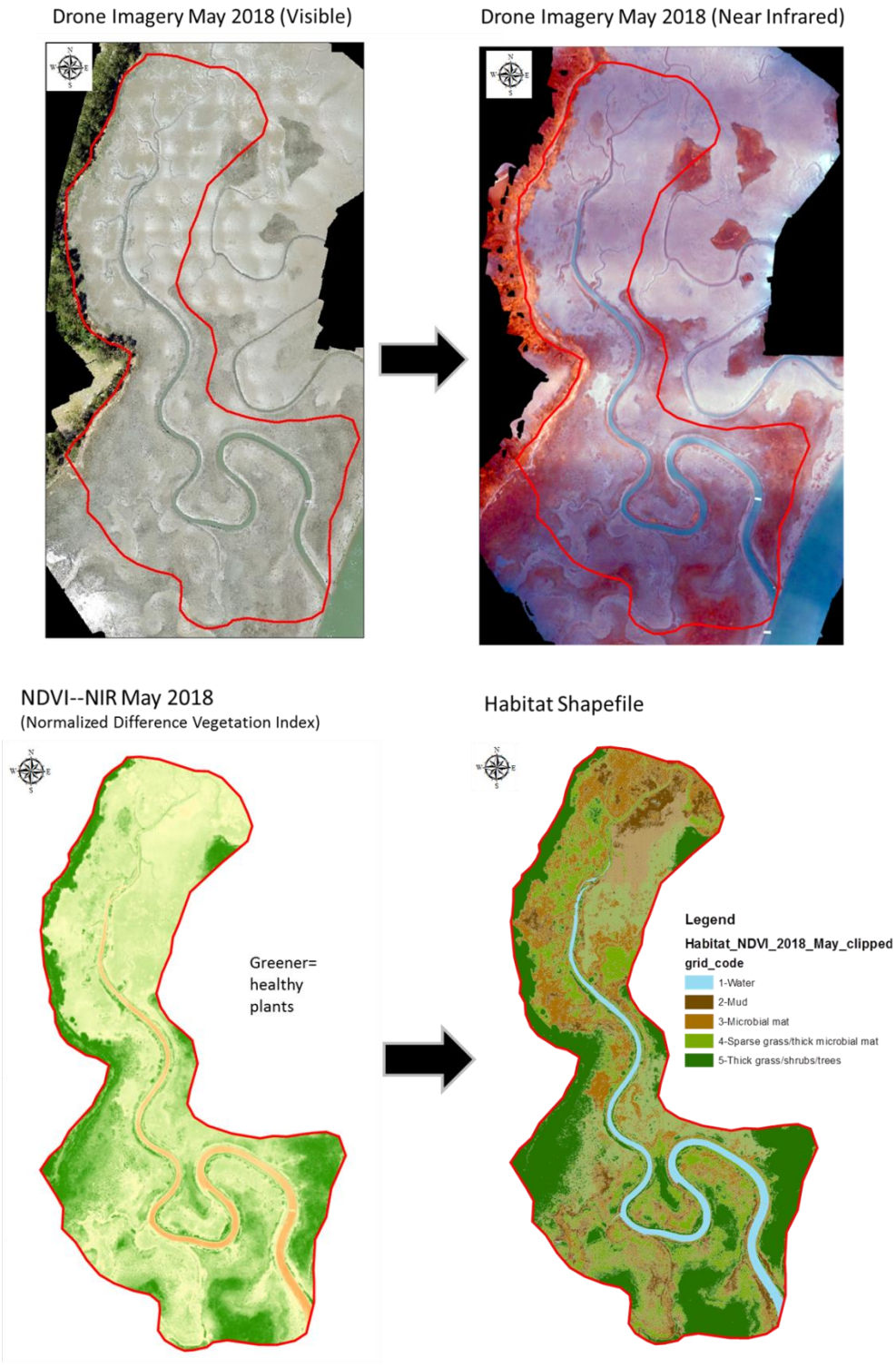

Fig. 6-2-3. Visible and near infrared orthomosaics collected in 2018. The specific study area is the red polygon. Imagery was clipped by this study area and post-processed using an NDVI algorithm which ultimately was used to create an ArcGIS shapefile for analysis.

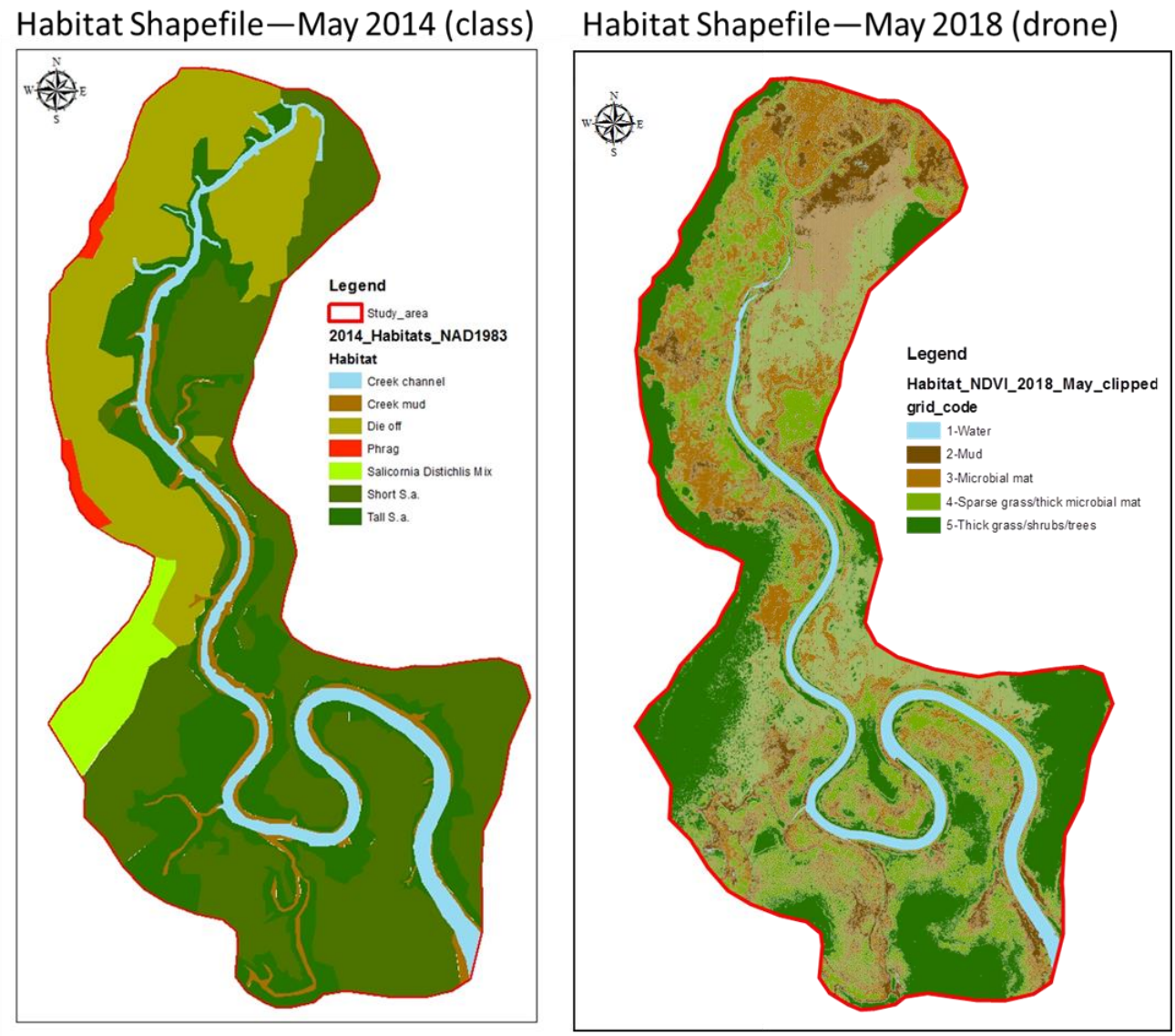

Fig. 6-2-4. Comparison of habitat shapefiles from 2014 and 2018 for a marsh dieback area near Wachapreague, VA. Note that legends/habitat categories differ due to differing methodologies (see text for details). "S.a." is the marsh grass, *Spatina alterniflora*. "Die off" in the right image would basically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

Chapter 6. Mapping Coastal Change

Section 6-3: Sediment Characterization

Authors: P.G. Ross and Richard Snyder

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

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 Area & Methods

We selected 108 and 93 sites in 2018 and 2019, respectively, spread evenly between each of the three EMP geographical areas, to map sediment (Figs. 6-3-1 & 6-3-2). These sites coincide with soft-sediment community sampling (see Chap. 5-1). Samples were stratified into 3 sub-habitats based on water depth: *intertidal* (exposed at MLLW), *shallow subtidal* (>0-1.5 m at MLLW) and *deep/channel edge* (>1.5-2.5 m at MLLW). See Chapter 5-1 for details of this

sampling which included both grab and push core samples (Fig. 6-3-3). At each of these sites we sub-sampled surficial sediment for organic matter (SOM) and benthic chlorophyll (Chla) concentrations. Subsamples to 1 cm deep in the seabed were collected at each location (~2 cm^2 aerial footprint). These samples were initially frozen at -4° C and -20° C, respectively.

The loss-on-ignition (LOI) was used to determine SOM. Samples were dried at 80-100° C to a constant weight (36+ hours). They were then allowed to cool, weighed (dry wt) and combusted in a muffle furnace at 500° C for 5 hr. Samples were subsequently re-wetted with deionized water and re-dried at 80-100° C to a constant weight (36+ hours). Samples were then re-weighed (ash wt). Ash-free dry wt and % organic matter were then calculated based on these results.

Chla samples were frozen in 15 ml polypropylene Falcon tubes (-20° C). Five ml of acetone (90%) was added to each tube which was then placed in a sonicating water bath for 15 minutes. Samples were immediately returned to -20° 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. Fluorescence of Chla was measured using a calibrated Turner Fluorimeter. Fluorescence of phaeophyton was then measured after adding 50 ul HCl to acidify the sample.

Additionally, sediment samples were collected at the grab locations in both years to describe sediment particle size fractions at depths 0-5 cm, 5-10 cm and 10-15 cm. Samples were immediately frozen. These samples have not been processed as of the writing of this report. The results from 2018 and 2019 will be reported in the 2020 report.

2018 & 2019 Results

In this report, we mainly summarize data for the grab sample locations (27 and 30 sites total in 2018 and 2019, respectively). GIS plots (2018 & 2019) and depth category graphics (2018 only) include both grab and core sampling locations (see below).

<u>Sediment Organic Matter (SOM)</u>

Overall at grab sample sites, mean SOM ranged from 0.09-7.22% and 0.03-6.00% during 2018 and 2019, respectively, with differences apparent between geographic areas and a slight decrease in each area between years (Table 6-3-1 and Fig. 6-3-4). Visualized data from all the samples in GIS exhibited macro geographic patterns with mean % SOM lowest in the Wachapreague Inlet area and higher in the coastal bay areas (Figs. 6-3-5 & 6-3-6).

As with other EMP components, we anticipate the main value of this data will be to document any substantial changes over time and multivariate comparisons of environmental factors with species distributions. As an example, in GIS we visualized changes from 2018 to 2019 for SOM (Fig. 6-3-7). The majority of sites had changes < 1.5% (+ or -), however several

had increases or decreases >1.5%. Without information on interannual variation from multiple years of sampling, it is impossible to ascribe a cause for the differences.

We examined the impact of water depth on sediment data from 2018 (as characterized by the three sub-habitat categories). In the case of SOM, the general geographic difference between the Inlet area and the others areas is apparent, but there was no consistent pattern between water depth categories overall or within geographic areas (Fig. 6-3-8).

Chlorophyll-a

Overall, mean surficial Chla ranged from 18-1,021 μg cm^{-2} and 6-156 μg cm^{-2} in 2018 and 2019, respectively. Chla exhibited macro geographic patterns that appear related to water depth and an inlet-to-enclosed-bay gradient (Figs. 6-3-9 to 6-3-12). It is not really appropriate to compare spatial patterns without consistent depth-specific Chla data for each sample in each region. However, we see a preliminary relationship to water depth by stratifying samples by the three sub-habitat categories which showed a similar pattern between geographic areas with the inlet area having lower measurements in the intertidal, but all geographic areas converging as water depth increased (Fig. 6-3-13).

Comparison to Previous Years

This is the first year that we have collected this type of data for the EMP. We do not have any previous data for these specific sites.

Discussion

Results for 2018 and 2019 are mainly reported as summary data. In future reports we plan to analyze these types of data statistically. However, several geographic patterns are apparent. Differences in SOM and Chla between the inlet area and the two coastal bays should be expected since the former is a much higher energy environment. We divided the geographic regions into the three sub-habitats based on water depth because we expected potential differences in communities and physical parameters. Based on 2018 results, this appears to be important to providing a broader picture of the status and, eventual, trends we see with various metrics such as those reported here. A much more extensive, higher spatial resolution gridded sediment sampling design is planned to begin in 2021 and bi-annually thereafter.

2018 Acknowledgements

We would like to thank Jazmine Evans, Evan Lawrence, Mary Holmes, Edward Smith, Sean Fate, Kirsten Travis and Hunter Leonard for field and lab assistance.

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Herman, P., J. Middelburg and C. Heip. 2001. Benthic community structure and sediment processes on an intertidal flat: results from the ECOFLAT project. *Continental Shelf Res*earch. 21: 2055–2071.

Seiderer, L. and R. Newell. 1999. Analysis of the relationship between sediment composition and benthic community structure in coastal deposits: implications for marine aggregate dredging. *ICES Journal of Marine Science*. 56: 757–765.

Table 6-3-1. Summary of mean surficial sediment organic matter (%) at grab sampling sites overall and within 3 geographic areas near Wachapreague, VA during 2018 & 2019.

Geographic Area	2018	2019	Average (2018-2019)	2019 vs. 2018	2019 vs. Avg.
All	3.2	2.5	2.9	-0.7	-0.3
Bradford Bay	4.2	3.6	3.9	-0.6	-0.3
Burton's Bay	4.1	3.3	3.7	-0.8	-0.4
Wach. Inlet	1.4	0.8	1.1	-0.6	-0.3

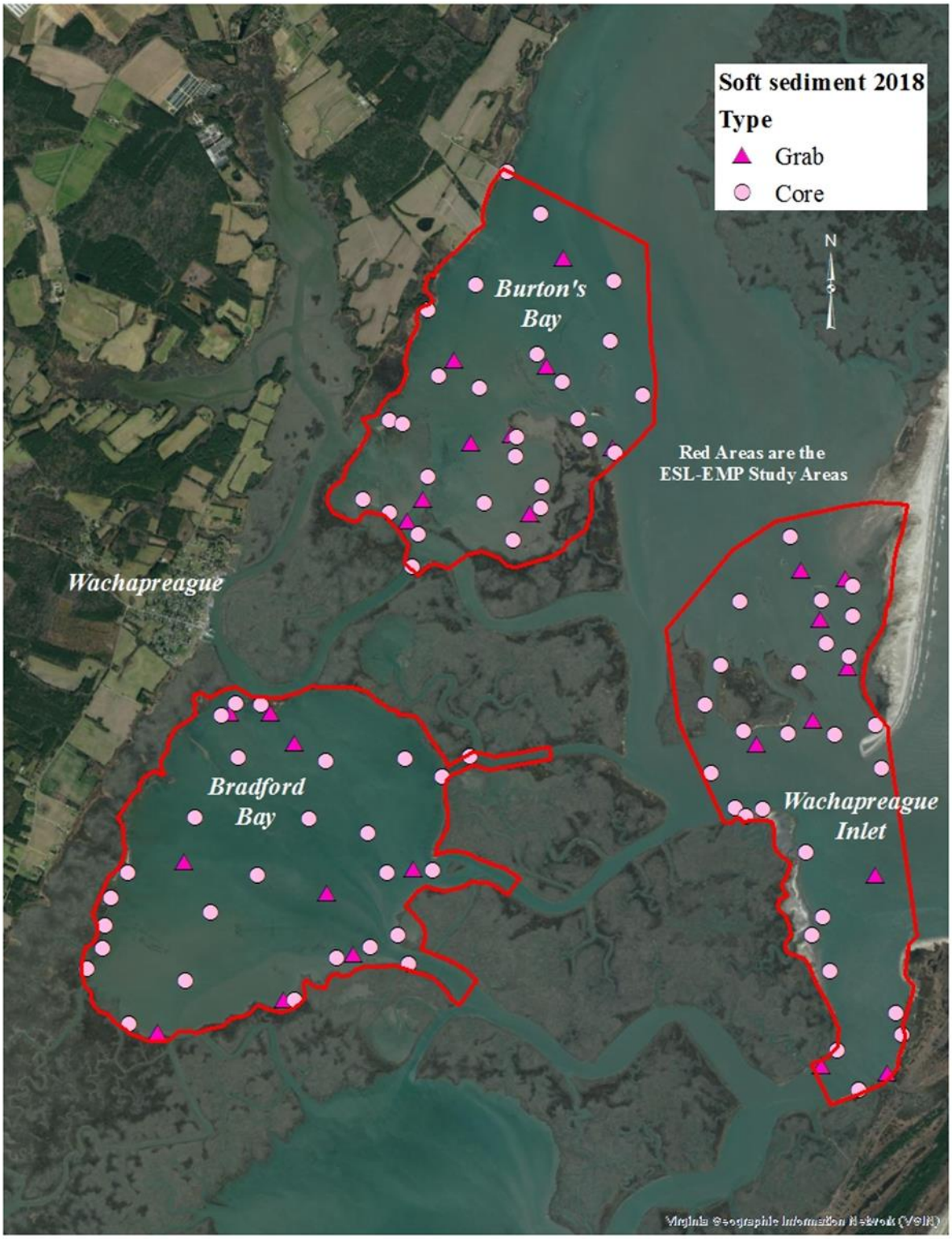

Fig. 6-3-1 Locations of 27 grab and 81 core sample sites where organisms were collected near Wachapreague, VA in 2018 (red polygons denote the ESL-EMP study areas).

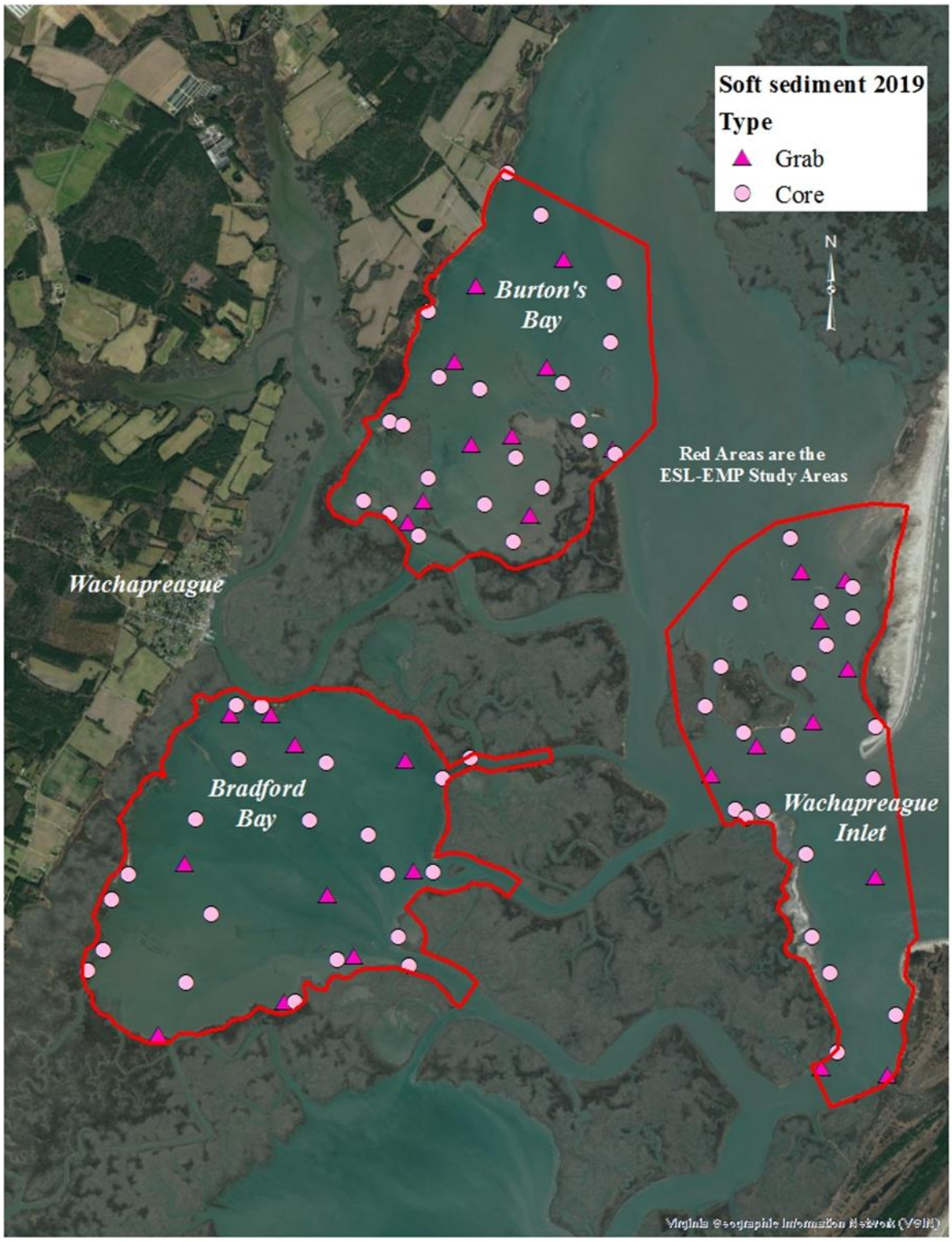

Fig. 6-3-2 Locations of 30 grab and 63 core sample sites where organisms were collected near Wachapreague, VA in 2019 (red polygons denote the ESL-EMP study areas)

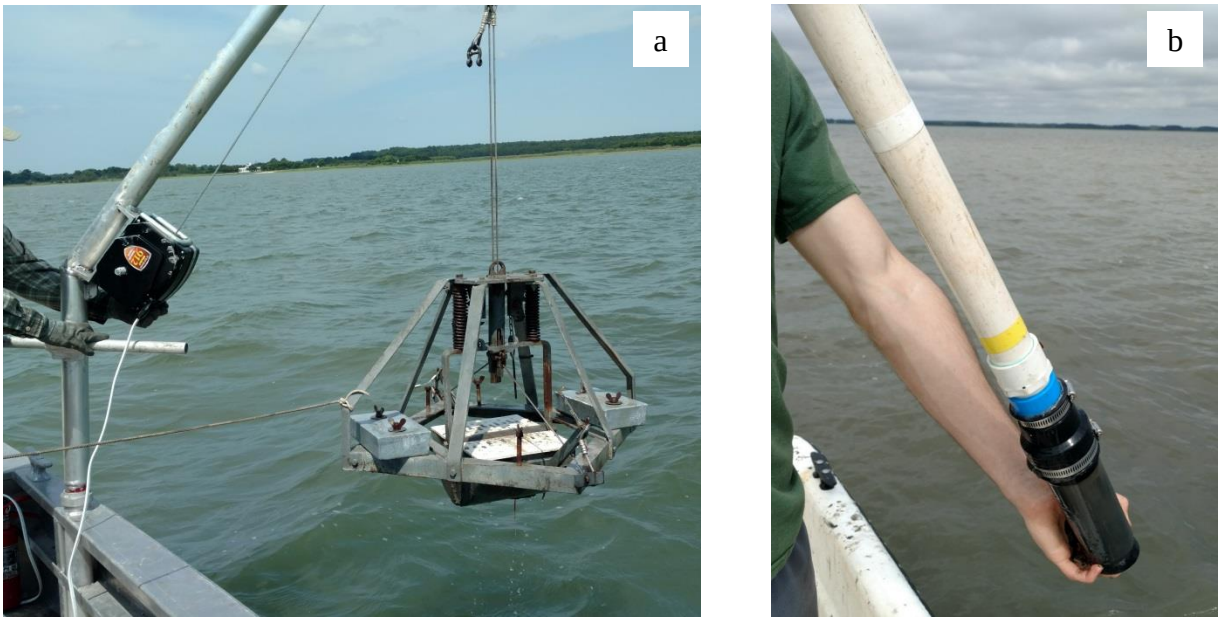

Fig. 6-3-3 Gear used to collect a) grab and b) push core samples; subsamples from these were collected for surficial sediment organic matter and chlorophyll-a.

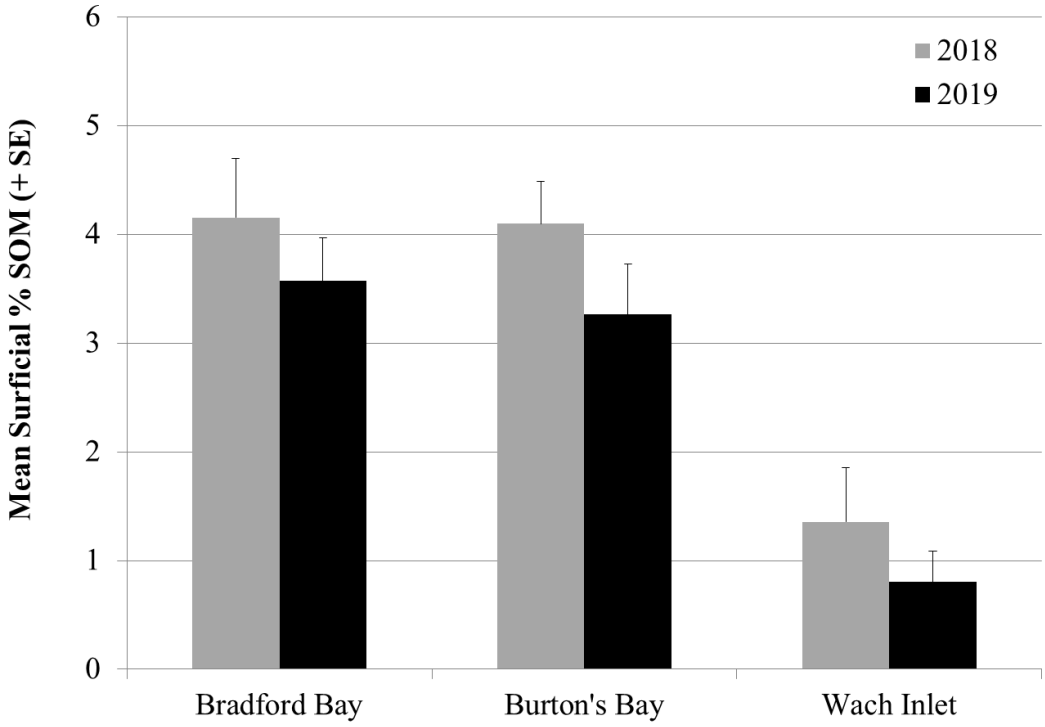

Fig. 6-3-4 Mean surficial % (+SE) sediment organic matter (top 1 cm of seabed) at grab sample locations within 3 different geographic areas near Wachapreague, VA in 2018 & 2019.

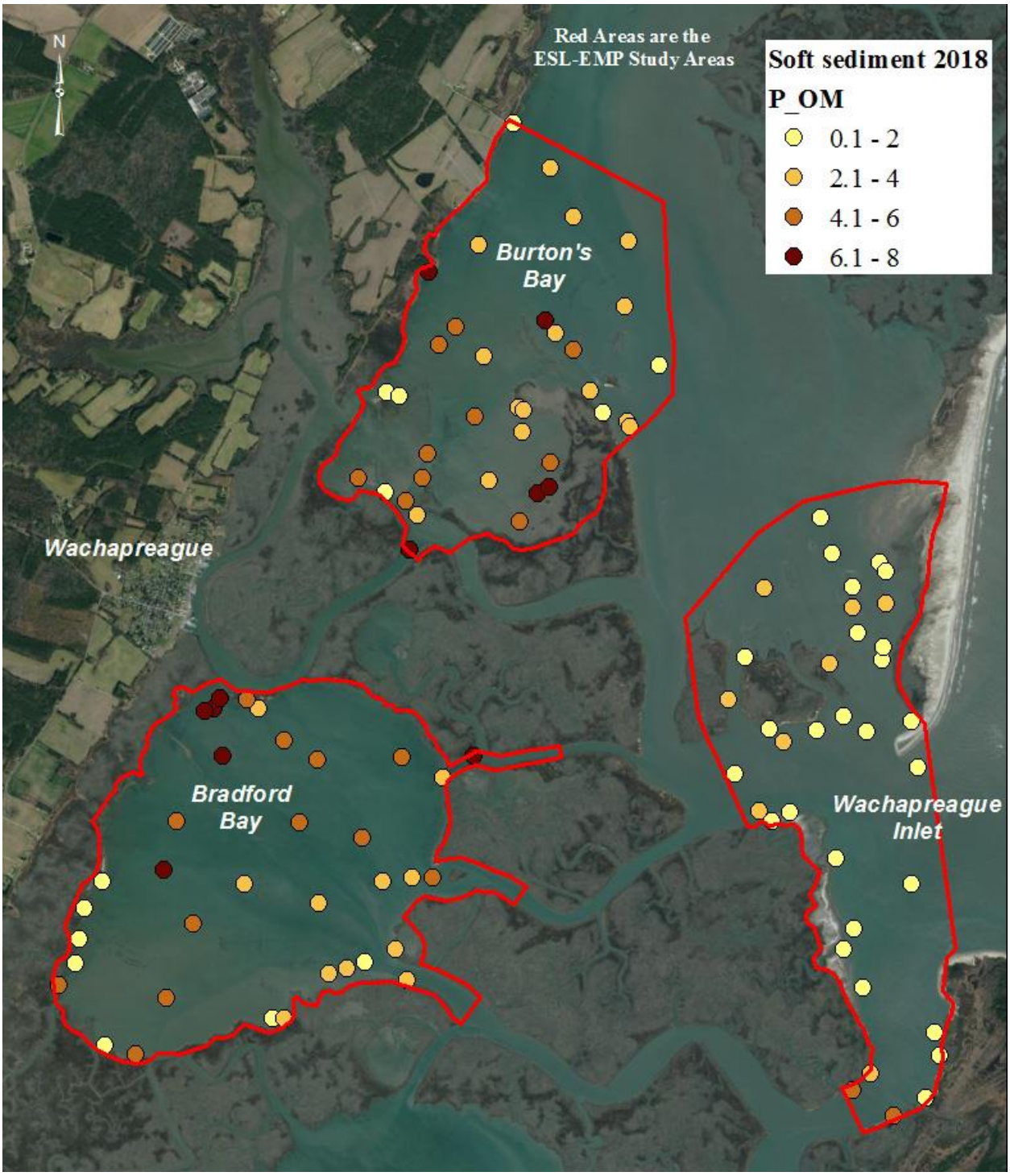

Fig. 6-3-5 Geographic visualization of surficial % sediment organic matter (top 1 cm of seabed) at 108 sites near Wachapreague, VA in 2018 (red polygons denote the ESL-EMP study areas).

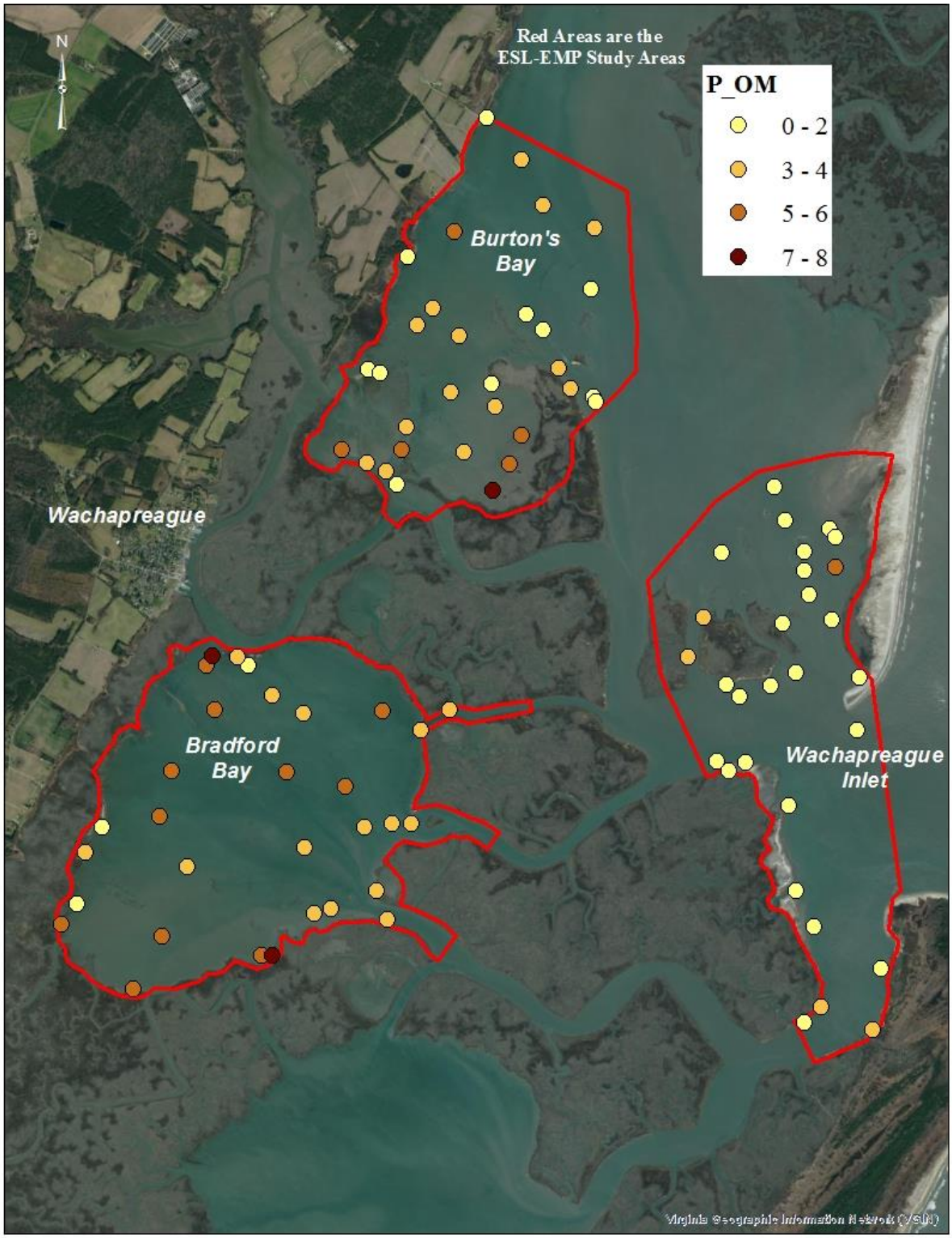

Fig. 6-3-6 Geographic visualization of surficial % sediment organic matter (top 1 cm of seabed) at 93 sites near Wachapreague, VA in 2019 (red polygons denote the ESL-EMP study areas).

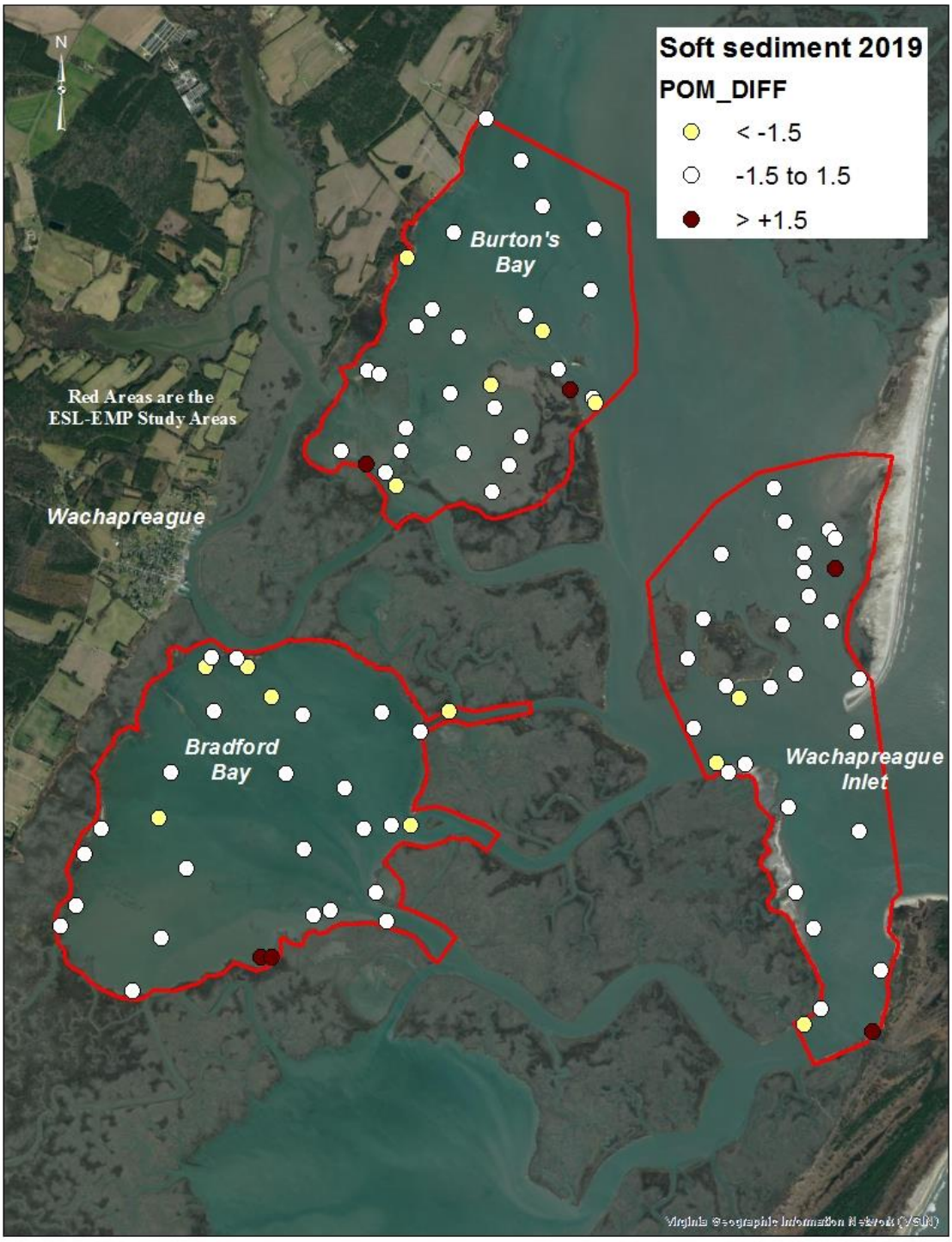

Fig. 6-3-7 Geographic visualization of the change in surficial % sediment organic matter (top 1 cm of seabed) at 93 sites near Wachapreague, VA from 2018 to 2019 (red polygons denote the ESL-EMP study areas). Changes of +/- 1.5% are considered to be similar based on the limited data collected so far and this visualization is mainly meant to be an example for analyzing change as the EMP progresses.

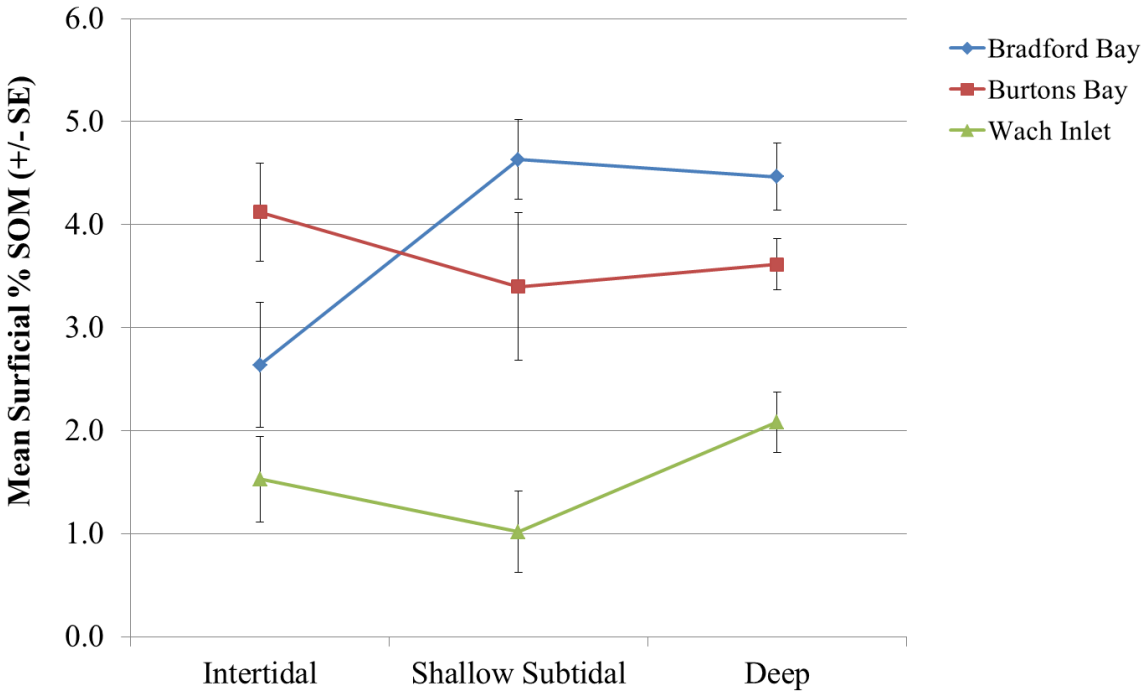

Fig. 6-3-8 Mean (+/- SE) surficial % sediment organic matter (top 1 cm of seabed) within 3 sub-habitat categories for 3 different geographic areas near Wachapreague, VA in 2018.

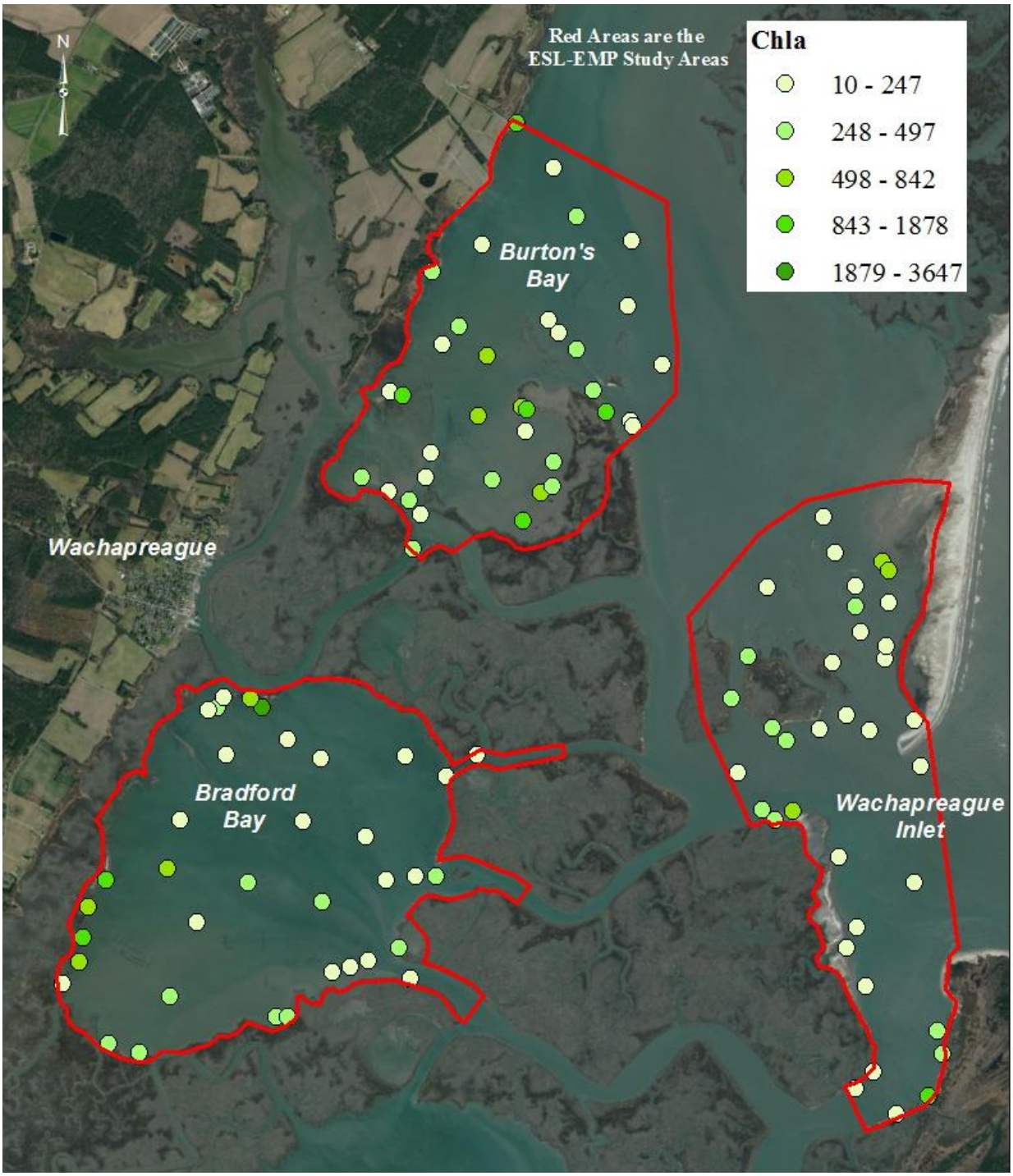

Fig. 6-3-9 Geographic visualization of benthic chlorophyll-a concentration (µg cm^{-2}; top 1 cm of seabed) at 108 sites near Wachapreague, VA in 2018 (red polygons denote the ESL-EMP study areas).

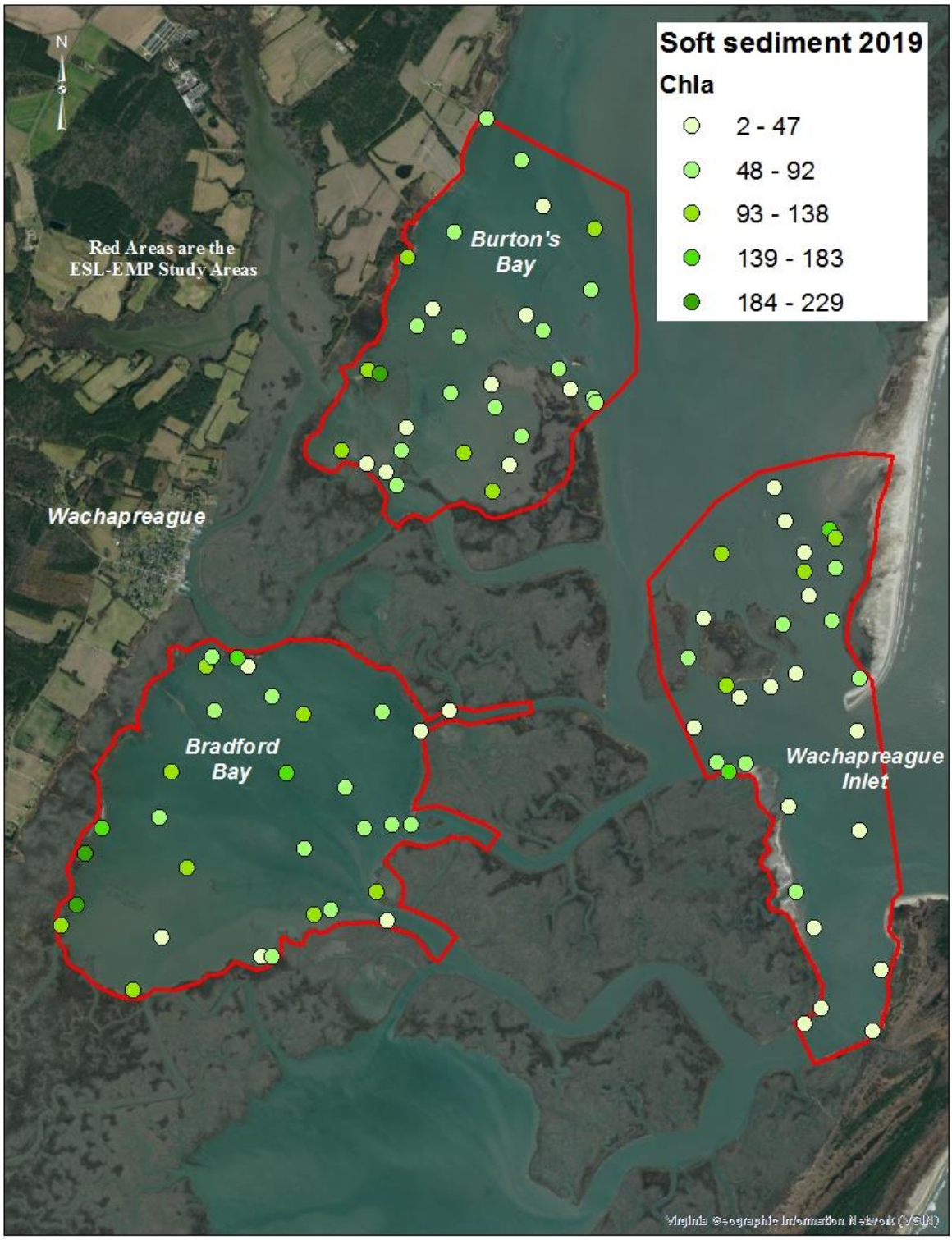

Fig. 6-3-10 Geographic visualization of benthic chlorophyll-a concentration (µg cm^{-2}; top 1 cm of seabed) at 93 sites near Wachapreague, VA in 2019 (red polygons denote the ESL-EMP study areas).

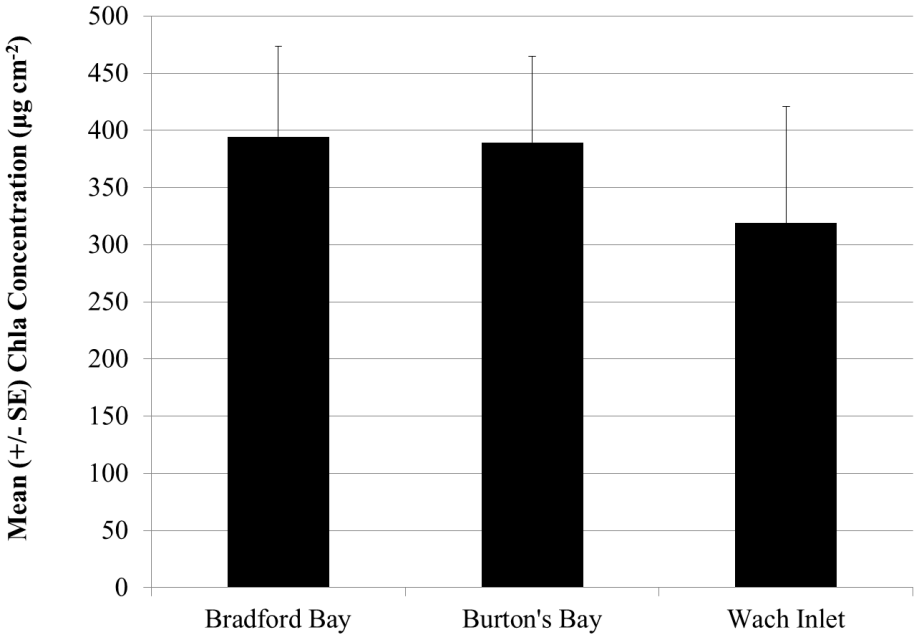

Fig. 6-3-11 Mean surficial benthic chlorophyll-a concentration (µg cm^{-2}; top 1 cm of seabed) for 3 different geographic areas near Wachapreague, VA in 2018.

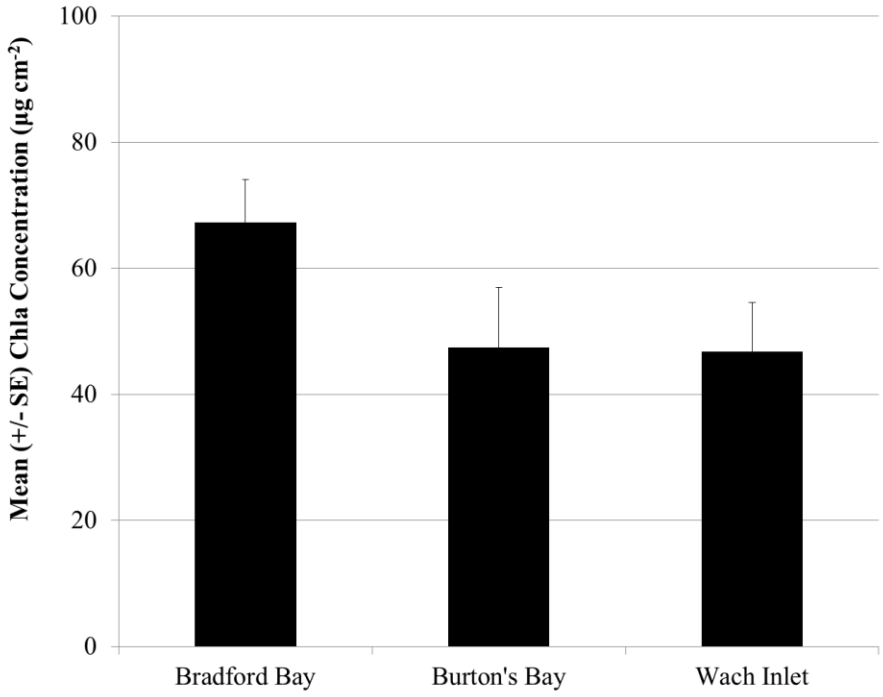

Fig. 6-3-12 Mean surficial benthic chlorophyll-a concentration (µg cm^{-2}; top 1 cm of seabed) for 3 different geographic areas near Wachapreague, VA in 2019.

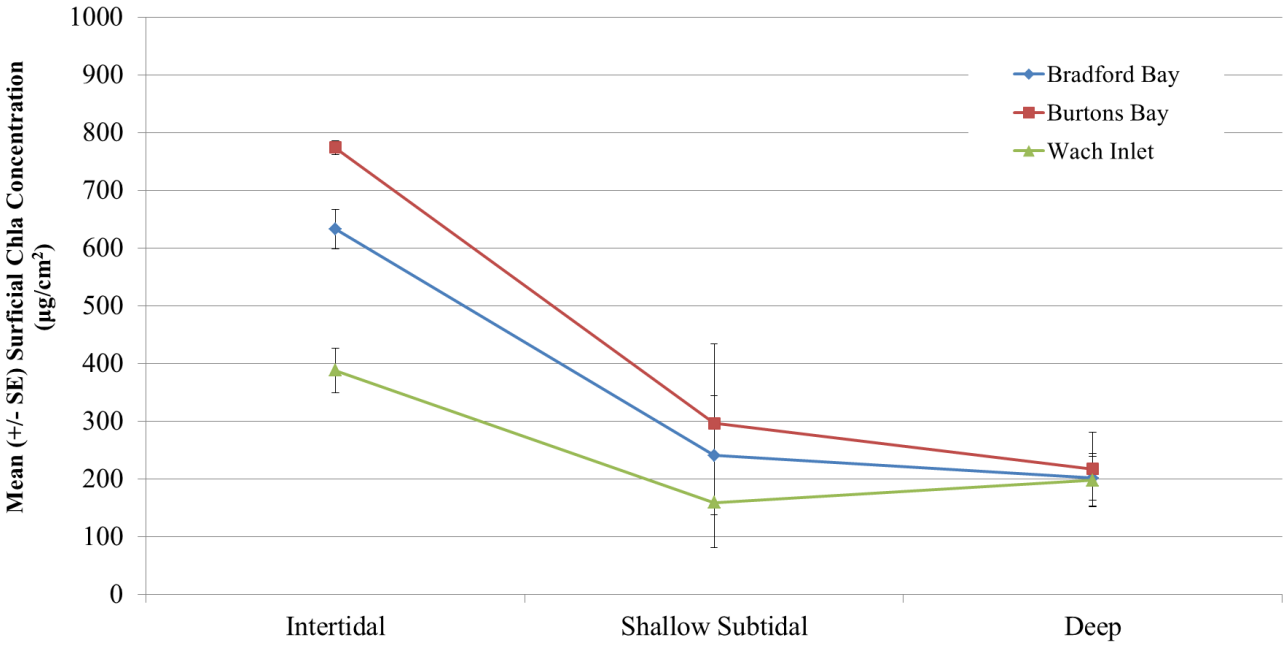

Fig. 6-3-13 Mean (+/- SE) surficial benthic chlorophyll-a concentration (µg cm^{-2}; top 1 cm of seabed) within 3 sub-habitat categories for 3 different geographic areas near Wachapreague, VA in 2018.