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# Ecological Monitoring Program at VIMS ESL: Annual Report 2023

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# Ecological Monitoring Program at VIMS ESL
# Annual Report 2023

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VIMS Eastern Shore Laboratory Technical Report No. 12

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

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# Contents

# 2023 Executive Summary

An Ecological Monitoring Program (EMP) has been established at the Virginia Institute of Marine Science Eastern Shore Laboratory (VIMS ESL) for the coastal environment near the Wachapreague lab. The goals of the initiative are to 1) provide status and trends information to scientists who study and regulators who manage Virginia's marine resources, 2) provide a scientific context for short-term research and grant proposals 3) provide pedagogical enrichment for educators to use in 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 of VIMS ESL in addition to our marine operations and shore support facilities. The EMP standard methods also provide visiting scientists and educators with protocols for consistent and comparable work and training. 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, Wachapreague Inlet dynamics and macroalgae distribution on mudflats. While this document focuses on these core areas of our monitoring activities, results of other VIMS ESL research on shellfish aquaculture, bay scallop restoration, and shorter-term grant supported research projects are reported elsewhere.

Real-time and archived water quality data, both the current electronic systems and records beginning in the 1960s, have been in demand by the aquaculture industry and scientists. In addition to summarizing 2023 data, we explore this data in the context of these historic water quality datasets. Weekly biofilm growth on standardized plates provides a biological sensor for water quality, system level microbial productivity, and microbial diversity. Data on oyster settlement rates reflects the present and potential future condition of seaside oyster populations, combining historical records with ongoing assessment. In 2023, annual cumulative spat set as high as 309,000 oysters per $m^2$ was recorded. Overall, it was the highest annual oyster settlement that we have recorded during seaside monitoring efforts. While this may bode well for seaside natural oyster reefs, there may be less positive impacts to aquaculture activities due to excessive fouling. Oyster population demographics in 2023 were similar to benchmarks established in 2018-2022, although there was a slight decrease in numbers and biomass in 2023. We also report additional data on oyster population biometrics. The soft-sediment benthic community was described based on data gathered from >1,200 individual organisms representing ~ 70 genera. We began sampling the nekton community in 2021-2022, and were able to continue to establish baselines in 2022 for late-spring, summer, and late-summer for these migratory and seasonal fauna based on >6,400 individuals representing >45 species.

The EMP has been supported by donations from Chuck and Janet Woods for operational expenses and an intern scholarship and other private 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 Program. During 2023, 4 local college undergraduate and 1 local high school students participated in EMP research activities.

The full report is available at the website: https://www.vims.edu/esl/research/emp/

# ***Section 1:  Ecological Monitoring Program (EMP) at the Virginia Institute of Marine Science Eastern Shore Laboratory (VIMS ESL)***

## Chapter 1. Context of the EMP

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The VIMS ESL mission is to serve as a field station and coastal seawater laboratory for basic marine science and aquaculture research, marine science education, outreach, and advisory service to the Commonwealth of Virginia, particularly with regard to marine resources and citizens 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 the VIMS ESL mission in three ways:

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

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

### Geographic Setting and Rationale

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

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

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

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

The need for such data is widely acknowledged, even if budget cycles and 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-minute 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. <u>Collect spatial and temporal data that provide environmental characterizations:</u> 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. <u>Establish status and trends for coastal environmental change analysis:</u> A lack of baseline and continuing environmental data hampers analysis of change and management of marine resources in the dynamic coastal ecosystems. VIMS ESL is uniquely situated to access unspoiled coastal marine habitats that integrate regional and global environmental impacts, and thus provides access and an excellent outdoor laboratory and sentinel site for broader environmental trajectories.

3. <u>Support aquaculture industry and commercial and recreational fishing communities</u>: 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. <u>Support student research and education:</u>

    a. *Provide research opportunities for VIMS and William and Mary students*. The VIMS-ESL has dedicated endowment funds 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 Program.

    The interns are provided summer employment and research experiences with ESL staff and visiting scientists. Projects and tasks within the EMP provide a wide range of training and experiences to assist interns in developing their careers.

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

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

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

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

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

# Chapter 2. Ecological Monitoring Program Overview-2023

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## Metrics

The EMP framework was designed to document the status and trends of environmental and ecological processes near the Eastern Shore Laboratory. Table 2-1 provides a list of data collected during 2018-2023. Details of specific data collection methods and locations can be found in the respective chapters. Sampling the nekton community was added 2021 and continued therafter with an additional season added in 2023.

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. 2-1): 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 and channel edge)
- Epi-benthic community: hard substrate (intertidal and subtidal)
- Nekton community: mobile macrofauna
- Sediment mapping (intertidal, shallow subtidal and 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 and marsh island mapping
- Macroalgal mapping

## 10-Year Plan

It is our intention that the EMP be a long-term dataset. To initiate the effort, we have developed a 10-year plan for collecting various metrics (Table 2-1). The potential for rates of change in the individual metrics was used to space effort temporally. The plan is subject to annual adjustment based on data results, funding, needs of visiting researchers and educators, and demands of other projects on staff and resources.

## Dissemination of Data

Data summaries and raw data will be made available to visiting researchers, students and the general public upon specific requests. The EMP program has been used in several grant proposals by VIMS and outside research scientists, adding a contextual backdrop and broader impacts to specific research plans. A course instructor (VIMS) who requested background data for a field trip out of ESL responded “This is perfect!”. The results of the EMP have also been made available through the following venues:

- VIMS ESL EMP Annual Report (this document): Annual report of EMP progress and results. This and previous reports are archived in William & Mary’s *Scholar Works*. Cumulative usage data, by report year, has been provided from W&M Scholarworks repository:

| Usage | 2018-2019 Report | 2020 Report | 2021 Report | 2022 Report |
|---|---|---|---|---|
| Abstract views | 220 | 150 | 166 | 96 |
| Download Count | 168 | 129 | 127 | 102 |

- Marine Life Day Display: Public open-house held on the third Saturday of September each year. Updated data for biodiversity and environmental conditions, analysis of status and trends for seaside ESVA.
- VIMS ESL dedicated webpage: The lab website has 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.
    - An overview of the EMP was presented as a poster at the Coastal and Estuarine Research Federation (CERF) biennial meeting in Portland, Oregon in November 2023: *The mid-Atlantic coastal marine ecological monitoring program at VIMS Eastern Shore Laboratory, Wachapreague, Virginia, USA* (Paige Ross and Richard Snyder**)**
    - Acknowledged in recent publication for mentorship and use of EMP data and oyster settlement protocols:

      Farmer MA, Klick SA, Cullen DW, Stevens BG. 2023. *Eastern oysters Crassostrea virginica settle near inlets in a lagoonal estuary: spatial and temporal distribution of recruitment in Mid-Atlantic Coastal Bays (Maryland, USA)*. PeerJ 11:e15114 DOI 10.7717/peerj.15114

## Student Involvement

Students from the institutions below participated in the 2023 EMP during May-August as part of the ESL summer internship program.

- Virginia Tech
- Old Dominion Universtiy
- University of Virginia
- Northampton High School

## Funding Gratefully Acknowledged

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

**Table 2-1**. VIMS ESL Ecological Monitoring Program 10-year sampling plan.

| Component | | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Yr 1 | Yr 2 | Yr 3 | Yr 4 | Yr 5 | Yr 6 | Yr 7 | Yr 8 | Yr 9 | Yr 10 |
| Water Quality | Water Quality: Fixed Sensor | X | X | X | X | X | X | X | X | X | X |
| | Water Quality: Data Flow | X | | | X | X | X | X | X | X | X |
| Biofilms | Biofilm Community | X | X | X | X | X | X | X | X | X | X |
| Oyster Population | Oyster Settlement | X | X | X | X | X | X | X | X | X | X |
| | Oyster Demographics | X | X | X | X | X | X | X | | X | |
| | Oyster Biometrics | | | | X | X | X | | X | | X |
| Clam Population | Hard Clam Settlement | | | | | | | X | X | X | X |
| Faunal Community Structure | Benthic Soft Sediment | X | X | X | X | Partial | X | | X | | X |
| | Epi-benthic Hard Substrate (Intertidal) | X | X | X | X | X | | X | | X | |
| | Epi-benthic Hard Substrate (Subtidal) | X | X | X | | X | | X | | X | |
| | Nekton Community | | | | X | X | X | X | X | X | X |
| Mapping Coastal Change | Wachapreague Inlet Shoreline | X | Partial | X | X | | | | VBMP? | | |
| | Finney Creek Marsh Dieback | X | | X | | X | | X | | X | |
| | Sediment Characterization | X | X | | X | | X | | | X | |
| | Macroalgal mapping | X | | X | X | X | X | X | X | X | X |

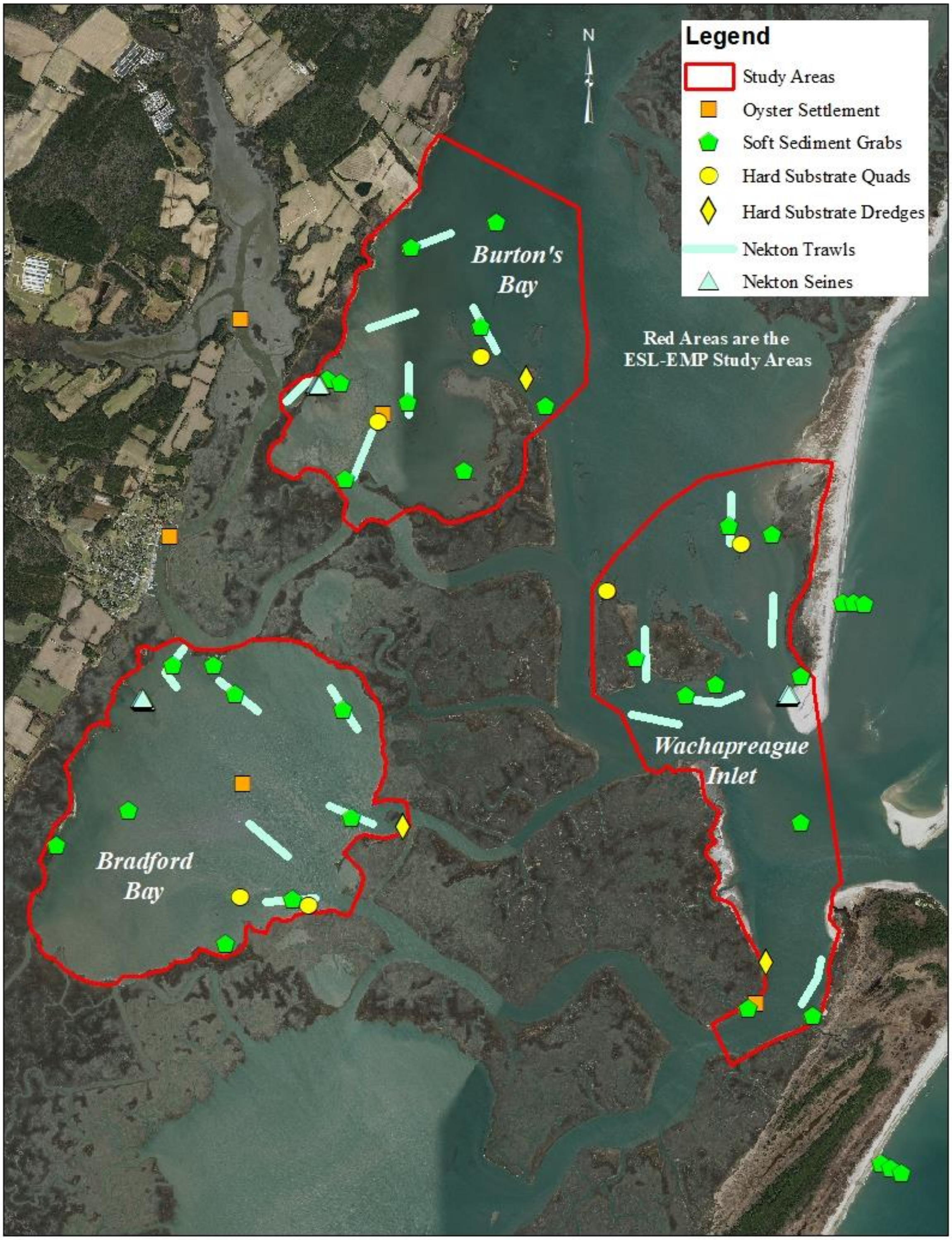

**Figure 2-1** Three geographic regions of the ESL-EMP with current sampling locations: Bradford Bay, a portion of Burton's Bay, and the Wachapreague Inlet vicinity. Additional samples were taken on the ocean side of Cedar and Parramore Islands in 2022-2023 (See Chapter 14).

# ***Section 2*: *Physical, Chemical & Geological Context***

## Chapter 3. Water Quality: Continuous Fixed Stations

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Complete | Complete | Planned |

### Introduction

The VIMS Eastern Shore Laboratory (ESL) has established continuously recording, fixed-sensor water quality monitoring stations using multiparameter sondes to provide real-time and archived data on the seaside of the Eastern Shore of Virginia. Continuous monitoring stations have been established at the following locations:

- Wachapreague (37°36'27.6912" N 75°41'8.9124" W) *RA Snyder VIMS startup funds*
- Willis Wharf (37°30'43.0806" N 75°48'22.1934" W) *Steve and Barbara Johnsen donation*
- Burton’s Bay (37°36'50.8896"N 75°38'13.434"W) *Virginia CZM Program, NOAA, and TNC*

Multiparameter sondes are also deployed intermittently at field sites to monitor for specific research projects. One example is the VIMS shellfish lease, an area often utilized for studies involving oysters and other ecological monitoring along Custis Channel, in the southeastern portion of Burton’s Bay (37°36'58.77" N 75°39'50.50" W). Live data (15-minute intervals) from the Wachapreague, Willis Wharf, and Burton’s Bay stations can be found at www.vims.edu/esl/research/water_quality/. Archived data from continuous stations and remote deployments are available upon request (contact Darian Kelley at dkelley@vims.edu).

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. These water quality datasets can be analyzed with other ecological monitoring data to elucidate how naturally occurring fluctuations and unique water quality events, correlate and impact marine ecosystems. Additionally, individual researchers and educators utilizing ESL facilities can access real-time and archived data for the period of their work, or longer-term records as desired. Requests for these data have come from researchers working at local, national, and global scales for research context, grant proposals, and tracking global changes. These water quality data can also be utilized to inform coastal zone management decisions by the Commonwealth of Virginia.

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

## Study Area & Methods

The Wachapreague station, installed in March 2016, was chosen to support research that occurs at and near VIMS ESL's Seawater Laboratory (SWL). This station 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 utilizing water in that area. The Willis Wharf 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. This type of setup allows water to drain out of the flow cell between sample periods, decreasing biofouling and extending time between routine cleaning and maintenance of sensors and equipment. This sampling method has been verified by comparison with an in situ submerged sonde reporting the same measurements. The Burton's Bay station was established to support seagrass and bay scallop restoration efforts in 2023 with grant funding provided by Virginia Coastal Zone Management (Virginia CZM) Program, the National Oceanic Atmospheric Administration (NOAA), and The Nature Conservancy (TNC). The Burton's Bay station is a remote monitoring station submerged at a fixed depth ~1.5 ft from the bottom. Data collected by the Burton's Bay station is collected in situ. To decrease biofouling of the sensors at the Burton's Bay Station, a ProbeGuard device is utilized (https://gescience.com/probe-guard/). Due to the well-mixed nature of seaside waters, both types of sampling methods (floating vs. fixed depth) will provide reasonable estimates of water column conditions. System control and reporting of live telemetry for the Wachapreague, Willis Wharf, and Burton's Bay stations was developed by Green Eyes LLC (Easton, MD).

Maintenance schedules vary depending on season and site location and are dependent on frequency and type of biofouling. The land-based Wachapreague and Willis Wharf stations are dual line systems that require weekly line changes to switch pump intakes. This consists of the removing and cleaning of one pump while another remains in service, minimizing biofouling of both the water lines and pump intakes. Since the pump intake is the only portion of the land-based systems that is constantly exposed to the marine environment, flow cell and sensor maintenance are minimal. Light cleaning of the flow cell wall occurs once or twice a month. The ProbeGuard device is advertised to minimize maintenance visits to a remote station for up to 3 months; though, ESL plans to visit the Burton's Bay station ~once a month to monitor fouling and equipment. Field deployed sondes typically require 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 gaps in the datasets, deployed equipment is immediately swapped with clean, calibrated equipment for maintenance of retrieved sondes.

Data for eight water quality parameters is collected at all ESL monitoring sites (Table 3-1). Water temperature, salinity, specific conductance, pH, dissolved oxygen, turbidity, chlorophyll-a, and blue green algae phycoerythrin (BGA-PE) levels are measured at 15-minute intervals using a YSI EXO2 Multiparameter Sonde. Dissolved oxygen, turbidity, chlorophyll, and BGA-PE 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 each reading to provide accurate measurements and prevent sensor biofouling.

Quality control and data management is an integral part of this work. Suspicious spikes or outliers within a dataset are most likely caused by marine objects (e.g., macroalgae, particulate matter, small fish, crabs, etc.) interfering with optical sensor readings. Microsoft Excel was used to exclude questionable data during ESL's quality control 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 co-located with 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.

Weather and rainfall data relative to ESL water quality monitoring stations are also available through multiple organizations. Total rainfall is calculated weekly at ESL, and regional daily records are reported via the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS Network; https://cocorahs.org/viewdata/rainydaysreport.aspx). Regional weather archives are also accessible from the NOAA National Weather Service (https://www.weather.gov/akq/).

## 2023 Results & Discussion

Continuous water quality data was collected at Wachapreague and Willis Wharf during 2023. Minimums, maximums, and averages for temperature, salinity, pH, dissolved oxygen, turbidity, chlorophyll, and blue green algae are summarized in Table 3-2 (Wachapreague) and Table 3-3 (Willis Wharf). The Burton's Bay data collected in November and December 2023 has been omitted from this year's report but is available upon request (contact Darian Kelley at dkelley@vims.edu).

Continuous measurements allow analyses of seasonal and tidal patterns. Figs 3-2 through 3-8 display the 2023 data for Wachapreague and Willis Wharf by parameter. Seasonal trends, such as warmer water temperatures and lower dissolved oxygen levels in the summer/fall, and cooler water temperatures and higher dissolved oxygen levels in the winter/spring, are recognizable (Figs. 3-2 and 3-5). Episodic events, such as the distinct salinity troughs observed at both stations in December (Fig. 3-3), are also visible. Monitoring at multiple locations provides insight as to whether episodic events are wide spread due to season, tidal cycle, weather events, etc., or the result of a site-specific variable/occurrence. For example, ground water flow into Parting Creek is often a more significant factor than it is for Wachapreague Channel (Ross and Snyder 2022; see Chapter 3).

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. 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.  With a 1.5-meter tidal amplitude, water quality measurements on seaside ESVA are strongly affected by tidal flow. Relatively fast dissipation of salinity depressions and tide and turbidity correlations are discussed in 2018-2019's EMP report (Ross and Snyder 2020; see Chapter 2-1). Observations such as these can be used by researchers and local hatcheries to effectively reduce filtration and minimize time and supply cost.

ESL water quality monitoring data has proved to be a useful tool in providing background information and baseline data about tidal and seasonal fluctuations, and yearly comparisons and trends for multiple researchers and organizations. ESL monitoring data has been specifically requested for understanding ranges and extremes of temperature, salinity, pH, and dissolved oxygen that local organisms are experiencing during years, seasons, tidal cycles, and leading up to, during, or after unique events. Background data has been requested to understand what/if environmental factors relate to: patterns in fish dynamics in restored seagrass, microsite variation of sea anemones, and boring sponge and mud blister worm infestation in oysters. Total numbers of ESL water quality requests and requesting organizations are summarized in Table 3-4.

ESL monitoring data is also utilized by local aquaculture operations to identify and/or correlate notable events in production, growth, performance, and survival in relation to water conditions. Continuous monitoring data can be compared with significant events or trends in multiple stages of commercial aquaculture including hatchery, nursery, and grow out events. By maintaining comparable stations at both Willis Wharf and Wachapreague, VIMS ESL has been able to assess site-specific dynamics affecting hatchery production. Comparisons have been utilized between specific months during different years, and during the same days between stations to analyze local hatchery events. ESL water quality data has also been utilized in ESL's shellfish nursery to compare growth of genetic lines between years and to observe differences between grow out locations. Monthly water quality files are provided to two local commercial shellfish hatcheries, in addition to the real-time data provided through ESL's webpage.

ESL's continuous monitoring stations are displayed on 2 regional interactive maps used to consolidate and catalog water quality monitoring efforts. The Virginia Estuarine and Coastal Observing System (VECOS; http://vecos.vims.edu/Default.aspx), provided by the Chesapeake Bay National Estuarine Research Reserve – Virginia (CBNERR-VA), displays water quality and meteorological data available in Virginia's portion of the Chesapeake Bay and its associated tributaries. The Mid-Atlantic Ocean Data Portal (https://portal.midatlanticocean.org/), provided by the Mid-Atlantic Regional Council on the Ocean (MARCO), is an interactive mapping platform used by state and federal agencies, fishery management councils, industry, and community leaders to visualize ocean resources and improve ocean health in New York, New Jersey, Delaware, Maryland, and Virginia.

Water quality data from Wachapreague, Willis Wharf, and Burton's Bay 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. Alternate forms of environmental context complementary to ESL's monitoring data is available through the University of Virginia's Virginia Coast Reserve Long-Term Ecological Research (VCR LTER) program (https://www.vcrlter.virginia.edu/home2/).

## Comparison to Previous Years

Combining multiple years of monitoring allows data to be visualized and compared for identifying trends, changes, or episodic events. Seasonal trends, reported in the Results and

Discussion section above, are consistently visible across the multi-year datasets. Yearly minimums and maximums for the recorded parameters are also similar (Figs. 3-2 through 3-8). Salinity variations between years commonly correspond with weather events. Notable differences in salinity correlate with differences in precipitation reported by the CoCoRaHS Network.

Water temperatures in Wachapreague and Willis Wharf appeared lower than previous years of collected data during mid-May through the end of June 2023 (Fig. 3-2). To examine this difference more closely, the difference in daily average water temperature for 2023 was compared to all previous years for May and June in Willis Wharf ($WT_{2023}–WT_{avg2019-2022}$) (Fig. 3-9 A and B). The visible distribution of points below the red line in Fig. 3-9B indicates the majority (76%) of days in May and June of 2023 were cooler than the averages of the same days in 2019-2022. On average, days in May and June of 2023 were 1.26±2.45°C cooler than the previous 4-year average. Additionally, the daily temperature variation (minimum daily temperature to maximum daily temperature) for May and June 2019-2022 was 2.96 ± 1.14°C on average, but only 2.27±0.95°C for May and June of 2023. In Virginia, May and June are important months leading up to wild oyster and scallop spawning during late spring/early summer. Lower water temperatures during late spring/early summer could have an effect on timing and magnitude of spawning events, growth, and survival of local species. Observing and identifying yearly variations between years and seasons can assist in explaining fluctuations in species richness, abundance, and distribution in the future.

As we accumulate more years of water quality data, multi-year datasets can be used to establish ranges and visualize how current data compares to historical data, such as the historical water temperature comparison in Chapter 16. Continuous water quality monitoring will also help us visualize connections and draw inferences with the EMP species data. 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

I would like to thank Justin Paul, Glenn Brundage, Richard Snyder, Brian Manley, Edward Smith, and Sean Fate for fabrication and field assistance; Green Eyes LLC for system design and software troubleshooting; VIMS ITNS for networking and telemetry support, and PG Ross for facilitating webpage updates. We would also like to thank Steve and Barbara Johnsen for providing startup funding for the Willis Wharf Station, and Cherrystone Aquafarms for providing site support and utilities. Lastly, we would like to thank the Virginia Coastal Zone Management Program (Virginia CZM), the National Oceanic Atmospheric Administration (NOAA), and The Nature Conservancy (TNC) for startup funding for the Burton's Bay Station.

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Ross, P. G., and Snyder, R. A. (2022) Ecological Monitoring Program at VIMS ESL: Annual report 2021. VIMS Eastern Shore Laboratory Technical Report No. 9. Virginia Institute of Marine Science, William & Mary. doi:10.25773/evhr-a810

**Table 3-1.** Description of eight water quality parameters measured at ESL's water quality stations using YSI EXO2 Multiparameter 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 | - | Availability of H+ ions (acidic or basic/alkaline) |
| 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 phycoerythrin accessory pigment found in blue-green algae (cyanobacteria). |

**Table 3-2**. Summary water quality data for the Wachapreague station at ESL during 2023.

Location: *Wachapreague (ESL)*
Time period: *Jan-Dec 2023*

| | Min | Max | Avg | SD |
|---|---|---|---|---|
| Temperature (°C) | 0.77 | 32.52 | 17.83 | 7.68 |
| Salinity (psu) | 16.62 | 35.36 | 31.61 | 1.59 |
| pH | 7.16 | 8.22 | 7.76 | 0.19 |
| Dissolved Oxygen (mg/L) | 2.25 | 11.75 | 7.27 | 1.88 |
| Turbidity (NTU) | 2.23 | 133.59 | 15.33 | 10.76 |
| Chlorophyll (μg/L) | 0.03 | 56.95 | 3.75 | 3.87 |
| Blue Green Algae (μg/L) | 0.01 | 136.21 | 10.78 | 9.80 |

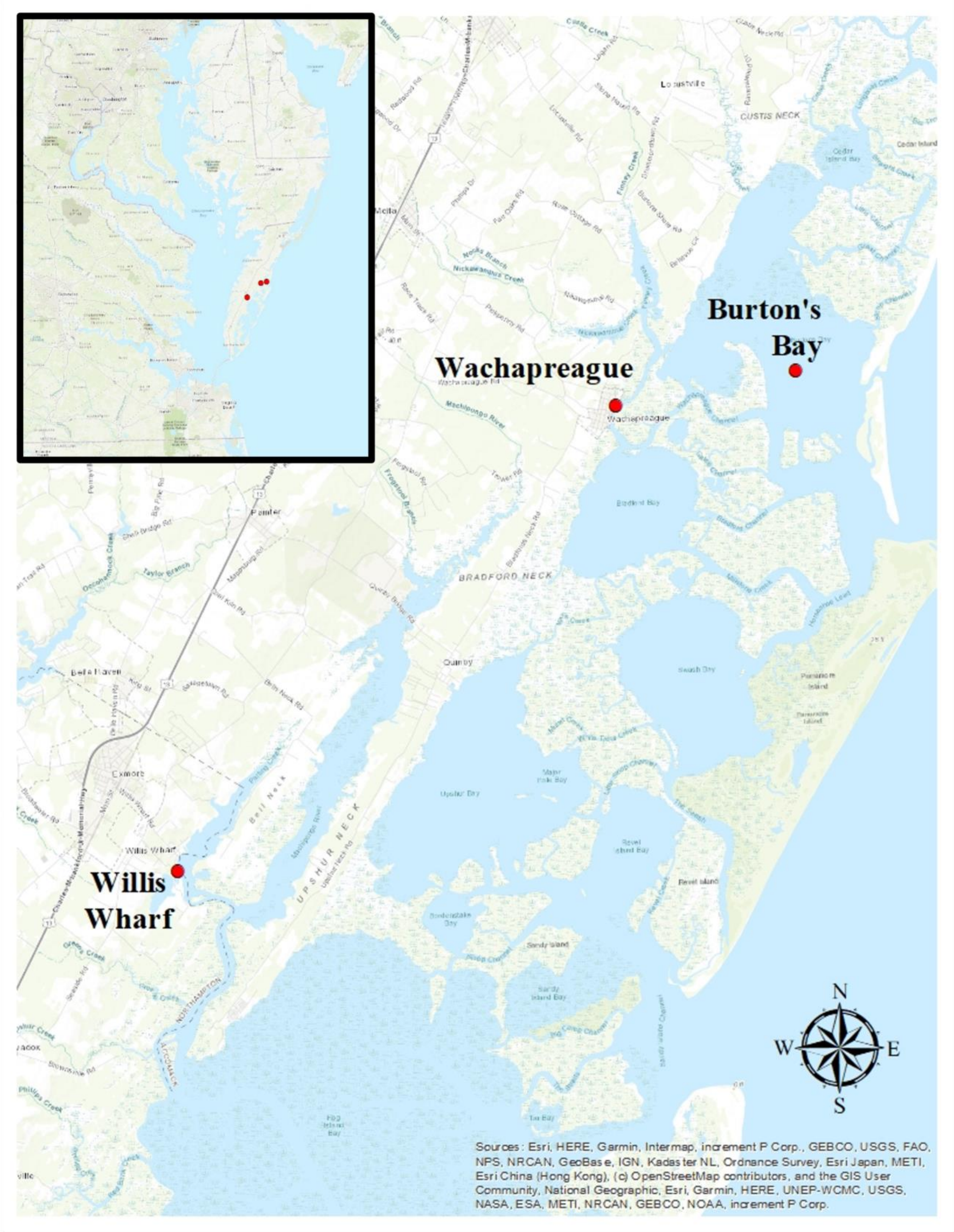
**Table 3-3**. Summary water quality data for the Willis Wharf station in Parting Creek during 2023.

Location: *Willis Wharf*
Time period: *Jan-Dec 2023*

| | Min | Max | Avg | SD |
|---|---|---|---|---|
| Temperature (°C) | 2.23 | 32.77 | 17.90 | 7.64 |
| Salinity (psu) | 13.58 | 34.14 | 30.64 | 2.31 |
| pH | 7.24 | 8.05 | 7.75 | 0.16 |
| Dissolved Oxygen (mg/L) | 2.42 | 11.63 | 7.45 | 1.92 |
| Turbidity (NTU) | 2.69 | 58.90 | 13.06 | 7.85 |
| Chlorophyll (μg/L) | 0.02 | 48.43 | 3.76 | 3.94 |
| Blue Green Algae (μg/L) | 0.31 | 109.43 | 9.42 | 8.06 |

**Table 3-4**. Summary of requests for ESL water quality data from 2016 to present. Organizations that received monthly data files were considered 1 request per year.
**The Willis Wharf monitoring station was installed October 2018.*
***The Burton's Bay was installed November 2023.*

| **Year** | **Total number of requests** | **Number of different organizations** |
|---|---|---|
| 2016 | 2 | 1 |
| 2017 | 5 | 2 |
| 2018* | 6 | 4 |
| 2019 | 12 | 8 |
| 2020 | 10 | 8 |
| 2021 | 15 | 7 |
| 2022 | 13 | 7 |
| **2023**** | **7** | **5** |
| Total | 70 | 16 |
| Average Per Year | 9 | 5 |



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

**Figure 3-1** Location of ESL's continuous water quality monitoring stations on the seaside of the Eastern Shore of Virginia.

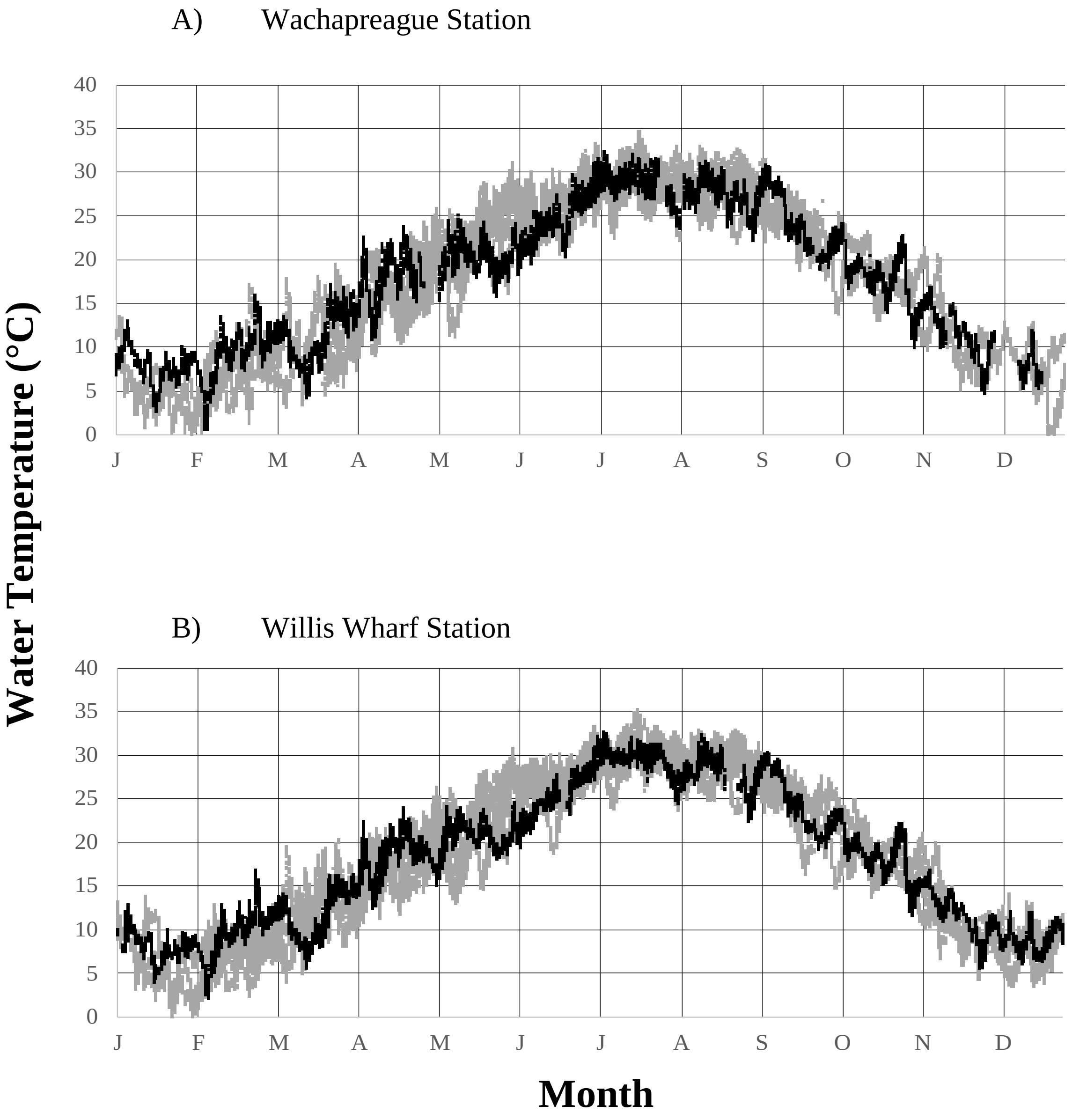
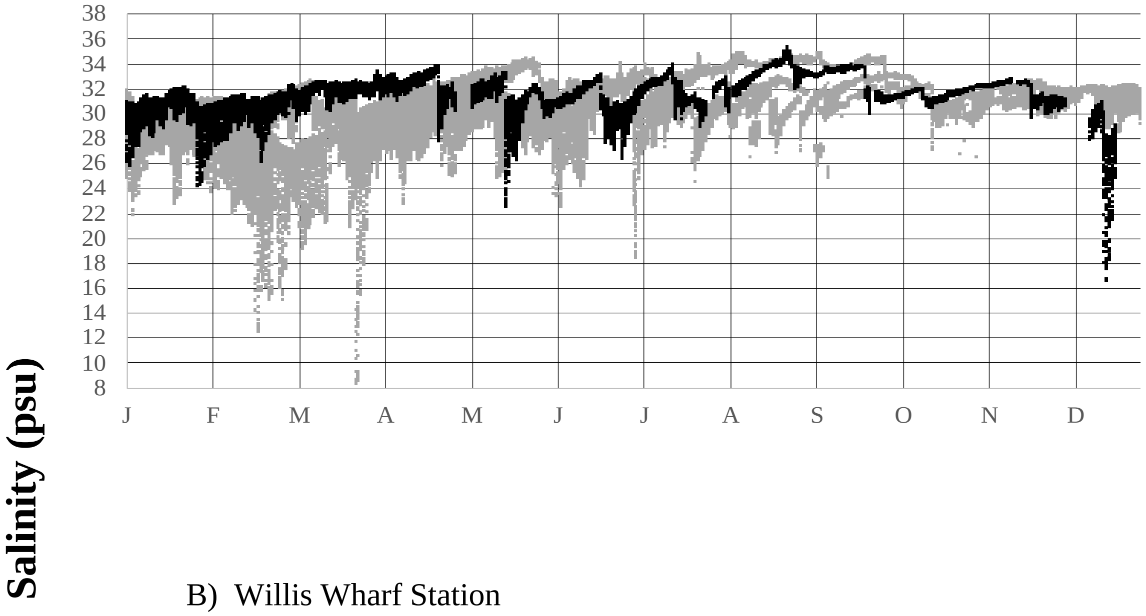


**Figure 3-2** Water temperature (°C) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

A) Wachapreague Station



B) Willis Wharf Station

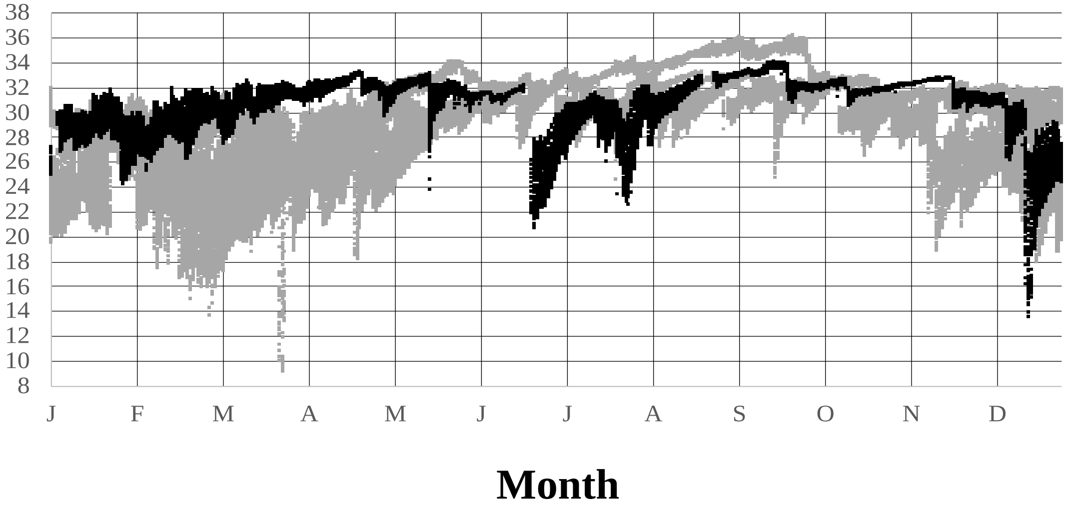
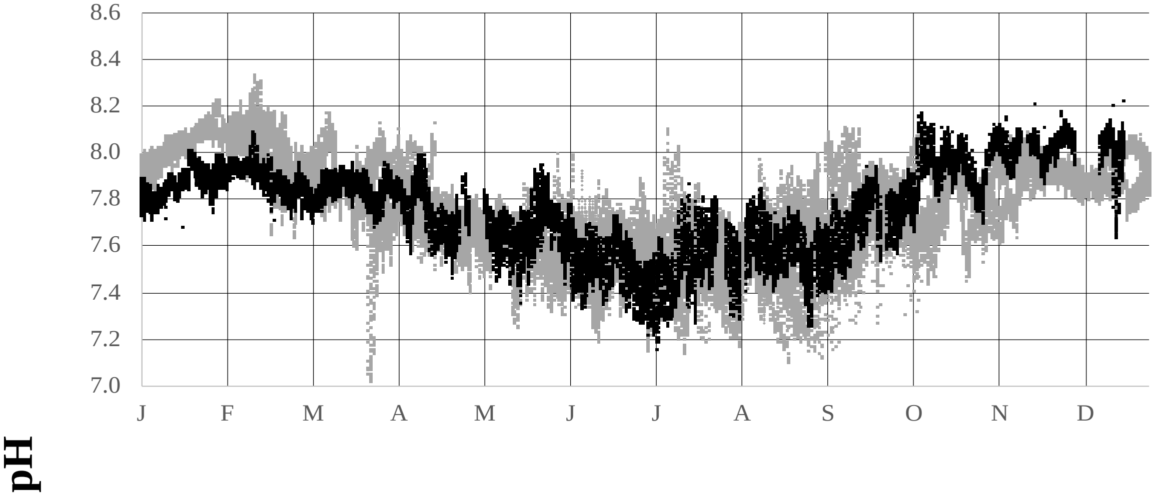


**Figure 3-3** Salinity (psu) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

A) Wachapreague Station



B) Willis Wharf Station

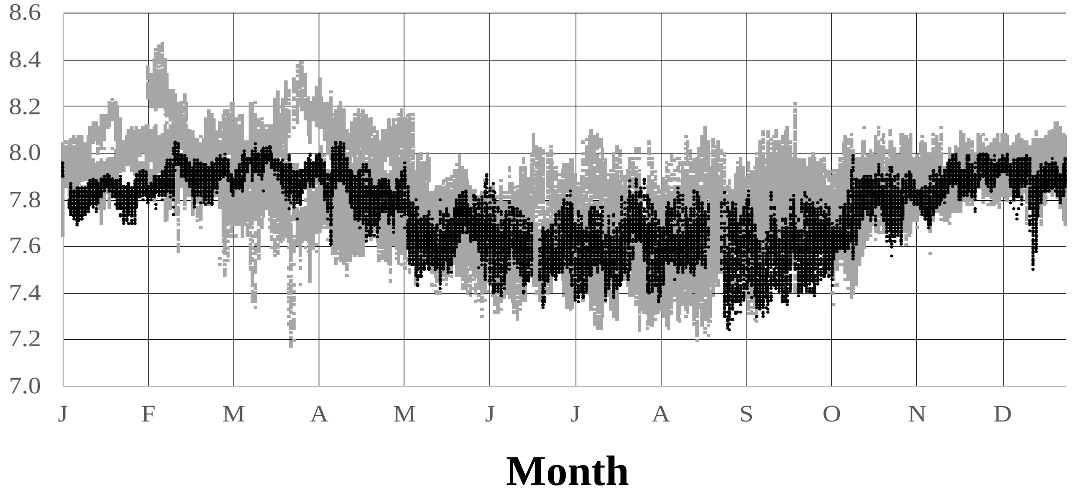


**Figure 3-4** Water pH (0-14 scale) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

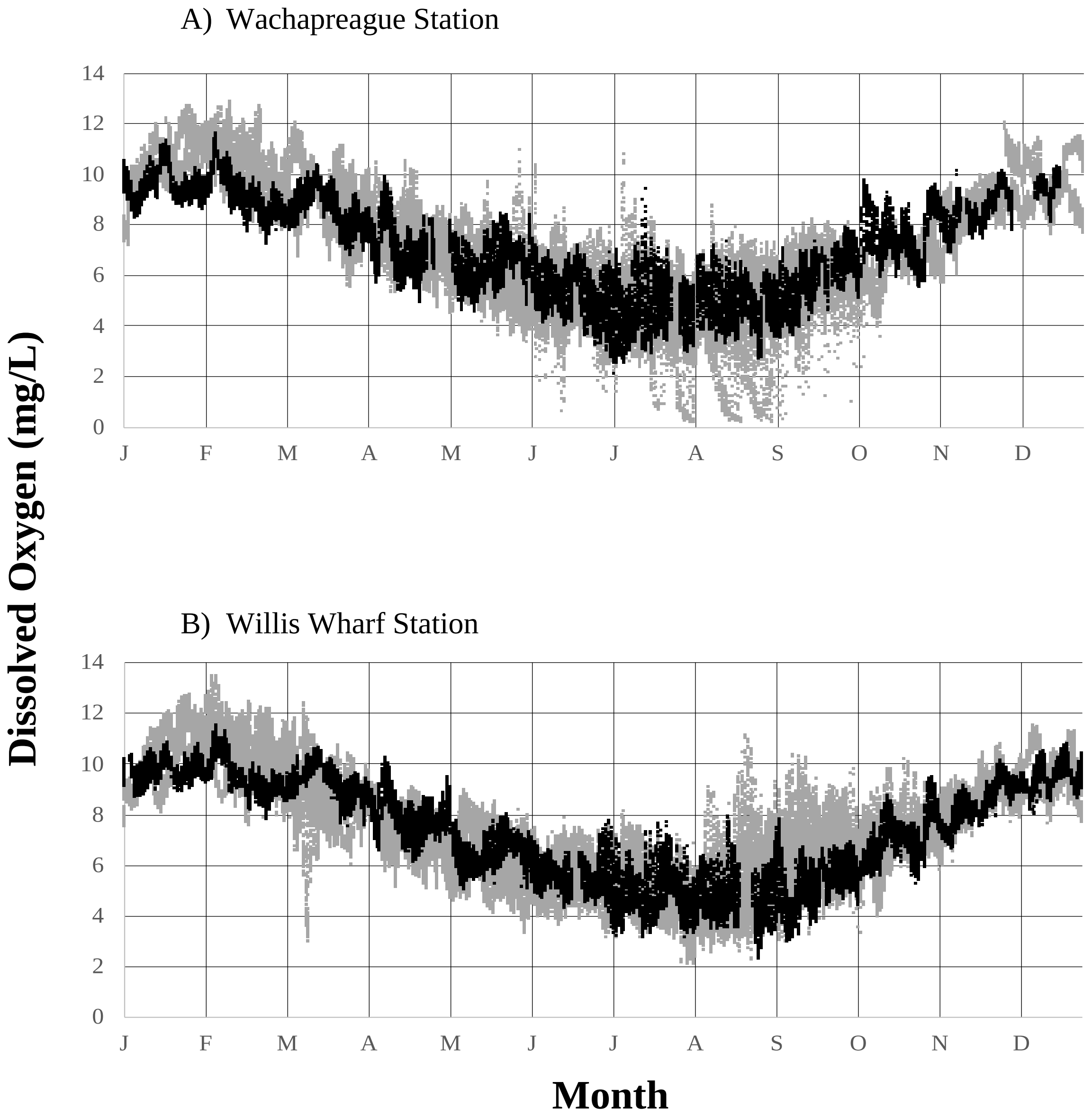
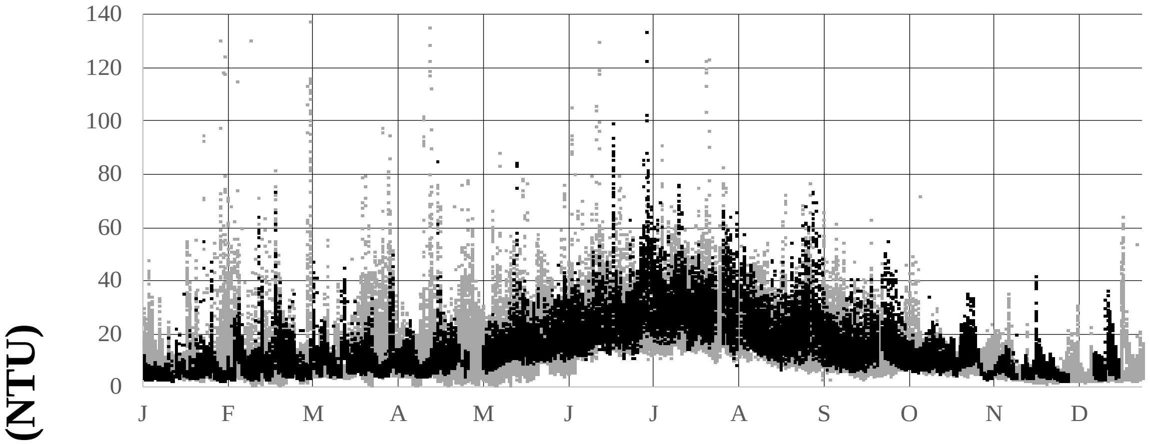


**Fig. 3-5** Dissolved oxygen (mg/L) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

A) Wachapreague Station



B) Willis Wharf Station

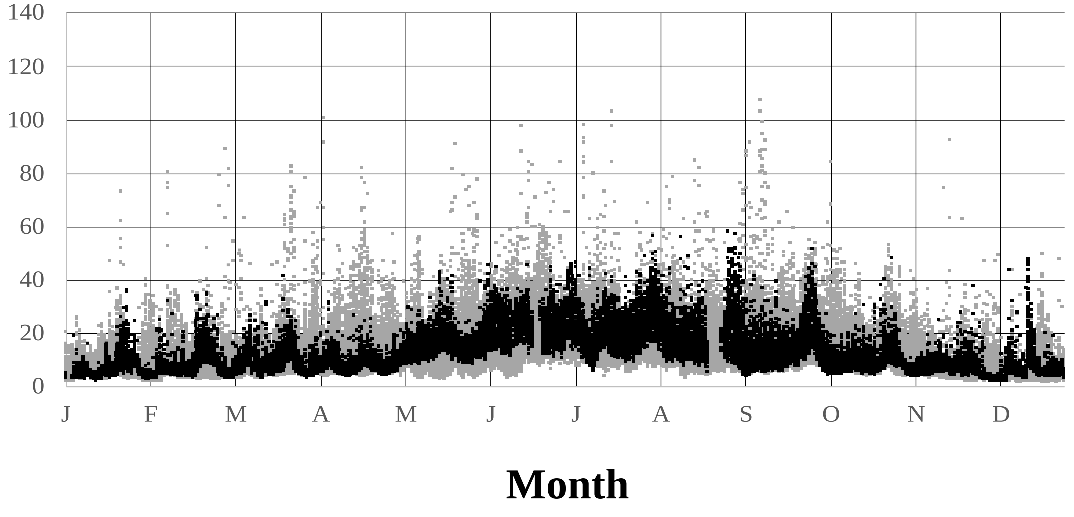
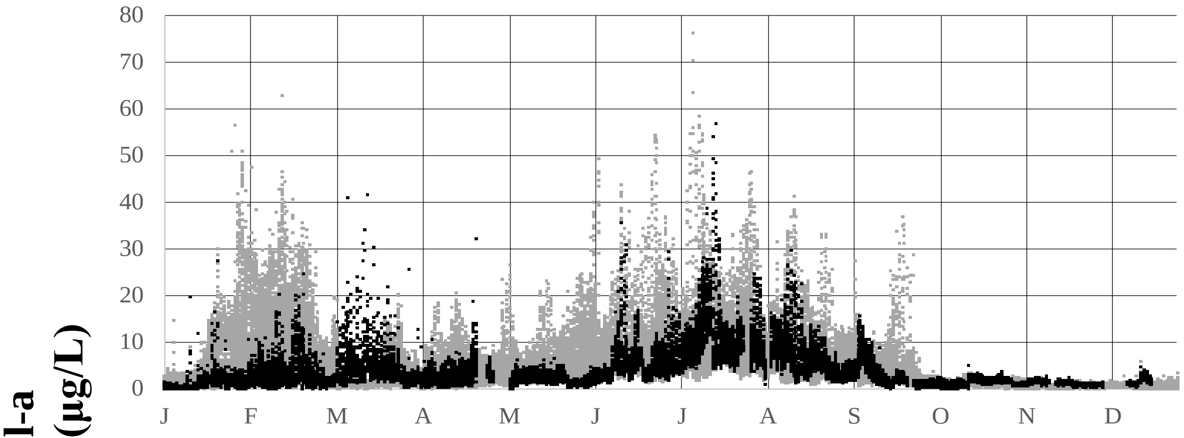


**Figure 3-6** Turbidity (NTU) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

A) Wachapreague Station



B) Willis Wharf Station

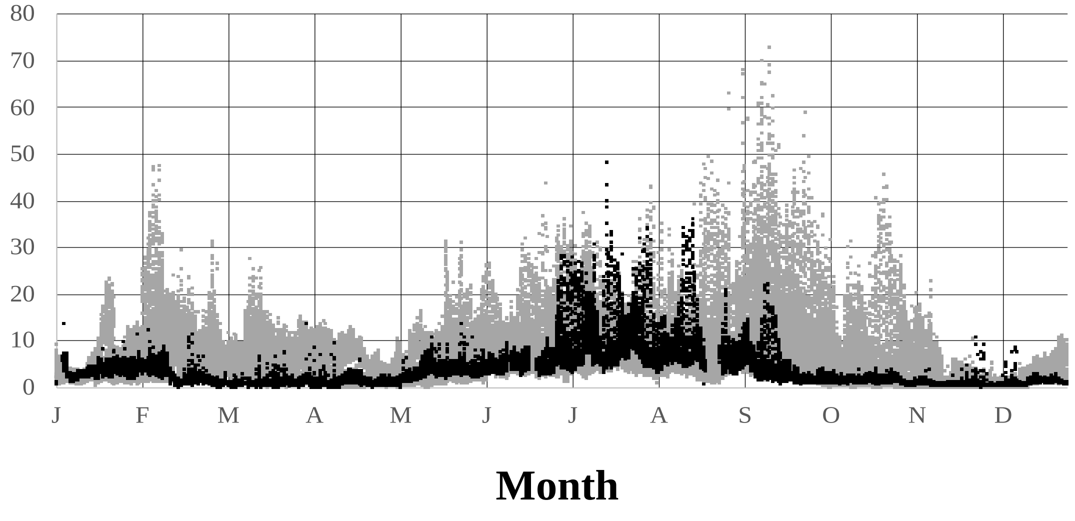


**Figure 3-7** Chlorophyll-a concentration (µg/L) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

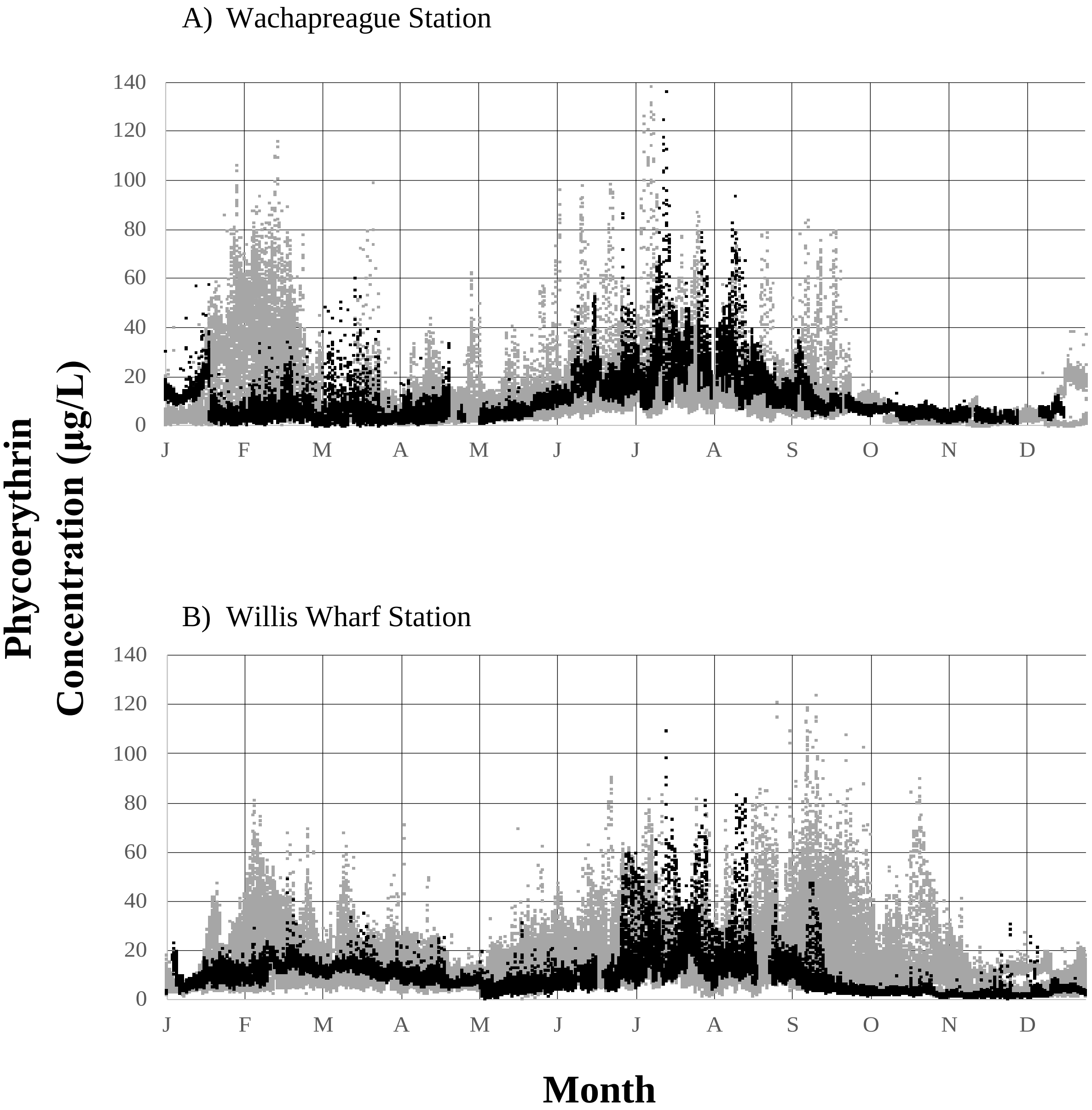


**Figure 3-8** Blue green algae phycoerythrin concentration (µg/L) for the A) Wachapreague and B) Willis Wharf water quality stations during 2023 (black) and all previous years collected (grey; 2018-2022).

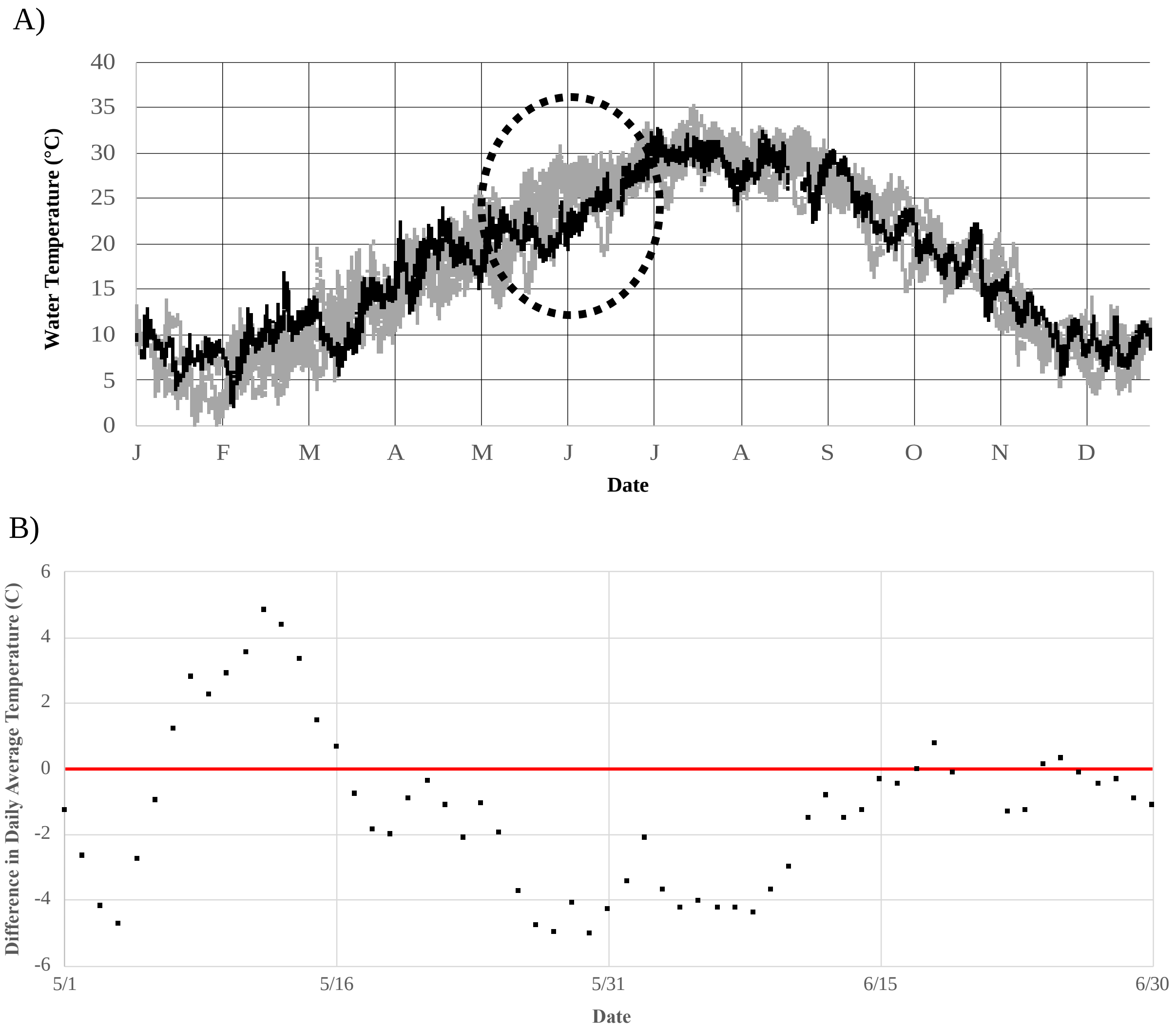


**Figure 3-9** A) Highlighting the visual water temperature difference in 2023 (black) compared to previous years (grey; 2019-2022) in Willis Wharf and B) The difference in daily average water temperature in Willis Wharf during May and June ($WT_{2023}–WT_{avg2019-2022}$; n=59).

# Chapter 4. Water Quality: Surface Water Mapping

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Partial |  | Cancelled (pandemic) | Completed | Completed | Completed | Planned |

## Introduction

Water quality data are often collected in a mixture of spatially and temporally focused efforts. Continuous measurement of water quality at fixed locations by data sonde stations provides temporally intensive data at a single point (see Chapter 3) but are spatially limited. Grab sampling strategies taken by personnel can cover a greater spatial extent, but are typically limited to widely spaced stations at single or spaced time intervals and are thus both temporally and spatially limited. Spatially intensive data over a short duration can be obtained by a system named Dataflow, described in this chapter. Each of these sampling strategies has limitations and benefits. A combination of these strategies can provide both spatial and temporal information on water quality trends that facilitate tracking changes in ecosystem processes and making decisions about the utilization of marine resources.

Dataflow is a vessel-based, continuous spatial data collection method using georeferenced sonde readings while a vessel is underway. The system was initially developed at VIMS (Moore et al., 2003) and has been implemented elsewhere. Surface water is pumped or hydraulically pushed into a flow cell chamber on a multiparameter water quality sonde (YSI EXO2 or equivalent). 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. The spatial resolution is controlled by frequency of readings and vessel speed. The spatial extent is limited to the travel time and range of the vessel, or time constraints such as a desire to collect data at low or high slack tides. We have taken this latter approach to remove confounding spatial patterns driven by changing tidal water flows. By acquiring data along a vessel track, spatial gradients in water quality conditions can be mapped within relatively short time windows to reflect the terrestrial-to-ocean gradient. These spatial data provide a different view of water quality trends to be coupled with the high-resolution temporal sampling at fixed-sensor stations (Chapter 3).

## Study Area & Methods

The dataflow system (Fig. 4-1) was deployed on a Carolina Skiff. On 26 July 2023, vessel tracks ran from Nickawampus/Finney Creek (north of the town of Wachapreague) to

Wachapreague Inlet via Wachapreague Channel, Burtons Bay and return through Millstone Creek, Bradford Channel, and Gates Channel into Bradford Bay. These tracks provide an inland to ocean spatial range coverage. Each cruise lasted about one hour covering both sides of low and high slack neap tides with minimal current flow. Low tide was 09:01EST @ 0.62 ft. High Tide was 15:41EST @ 4.26 ft. Vessel speed was 16 knots. Rain in the previous 12-18 hours was 1.5”. Winds during the run were SE 6 knots.

Eight water quality parameters were measured: water temperature, salinity, specific conductance, pH, dissolved oxygen, turbidity, chlorophyll-a, and photosynthetic bacteria pigment TAL PE (Table 4-1). These parameters were measured at 1-second intervals using a YSI multiparameter 6-port EXO2 Sonde. Dissolved oxygen, turbidity, chlorophyll, and TAL PE readings were determined using optical sensors (i.e. sensors that use a beam of light to calculate parameter measurements). Chorophyll and TAL PE were measured as relative Fluorescence Units (RFU) not calibrated to the actual pigment concentration, so they provide a relative view of photosynthetic pigment distributions. The EXO2 Sonde sensors were calibrated for other parameters 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).

Data were output from the YSI Kor software to .csv files in Microsoft Excel, and plotted using ESRI GIS software.

## 2023 Results & Discussion

Summary data for the low and high slack tide runs are presented in Table 4.2. Average suspended chlorophyll a was higher at low slack (2.53 RFU) than high slack (1.60 RFU), and was also more variable across the inland to inlet gradient (standard deviations 3.50 and 1.18 respectively). Cyanobacterial pigment followed the trend for chlorophyll a. The average and range of dissolved oxygen concentrations were higher when the system flooded with ocean water without change in variance. Overall salinity and total dissolved solids (TDS) changed very little with the tides. Turbidity was higher after flood tide than at low slack, with little change in overall variance. pH was slightly higher at high tide. Overall temperature was also relatively unchanged but the spatial variance in temperature was increased at high tide. The complete data sets are available upon request.

Spatial patterns in these parameters are displayed inthe GIS plots of Figures 4-3 to 4-8. The greater variance in temperature at high tide (Fig. 4-2) is likely due to solar warming of the extensive dark intertidal mudflats of the inland system during the day, especially in Nickawampus Creek. This diel temperature cycle would overwhelm any tideal influence and would have a dramatic effect on microbial processes in the water and in the benthos. With recent rainfall, freshwater input from Nickawampus creek is evident at high tide and more pronounced with the outflow of higher salinity water resulting in the pattern shown for low tide (Figure 4-3), although generally ocean water salinities dominate the system. Dissolved oxygen concentrations also suggest a diel and solar effect dominanting any tidal effects, with low values in the moring from over night respiration, and high values, especially in Nickawampus, from photosynthesis during the day in the water column and benthos (Fig. 4-4). However, an oxygen gradient from shallow inshore benthic respiration to oceanic water dominance is apparent for the low tide run. Spatial variance in turbidity was low, but turbidity values overall were higher after flooding tide, suggesting resuspension from the incoming flow, and particulate matter removal with the falling tide (Fig. 4-5). Changes in pH were relatively small, but show a consistent pattern of oceanic water flooding into the system with the tide (Fig. 4-6), but may also be affected by photosynthesis ramping up during the day between the morning low slack run and the afternoon high slack run. Algae biomass as chlorophyll a fluorescence (Fig. 4-7) follow an inshore to offshore gradient with higher concentrations in Nickawampus Creek and lower concentrations toward the inlet, a pattern the persists at both low and high slack tides, although at low water the algae biomass is higher in Nicawampus Creek than at high slack.

### Comparison to Previous Years

Nickawampus Creek continues to show the greatest variation in water quality parameters with tidal state, consistent with its location receiving freshwater stream flow. Recent rainfall prevented any inversion in salinities from inshore evaporation as seen in previous years. The shallow benthos of the system has effects on the water quality parameters of the system, but there is a clear oceanic dominance with limited influx of freshwater. The freshwater influx to the system is a contributor of nitrogen to this carbon rich system (Snyder and Ross, 2021).

### 2023 Acknowledgements

We would like to thank Darian Kelley, Justin Paul, and Glenn Brundage for sonde preparation and data flow system fabrication, and Emory Harned for on board asssitance.

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Snyder, R. A., and Ross, P. G. (2021) *Water quality in Accomack County Freshwater Streams 2020*. VIMS Eastern Shore Laboratory Technical Report No. 7. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/E73R-AM63

**Table 4-1.** Description of 8 water quality parameters measured using an EXO2 Sonde integrated in a Data Flow rig.

| Parameter | Unit | Description |
|---|---|---|
| Temperature | °C | Intensity of heat in the surrounding water |
| Specific Conductance | ms/cm | Conductivity of water for electrical current |
| Salinity | psu | Salts dissolved in a water sample |
| pH | - | Availability of $H^+$ ions (acidic or basic/alkaline) |
| Optical Dissolved Oxygen | mg/L | Amount of $O_2$ that is dissolved in the water. |
| Total Dissolved Solids | TDS mg/L | The amount of dissolved combined inorganic and organic substances |
| Turbidity | NTU | Suspended particulates in the water |
| Chlorophyll | µg/L | Chlorophyll a from algae |
| Blue Green Algae | µg/L | Phycoerythrin found in blue-green algae (cyanobacteria). |

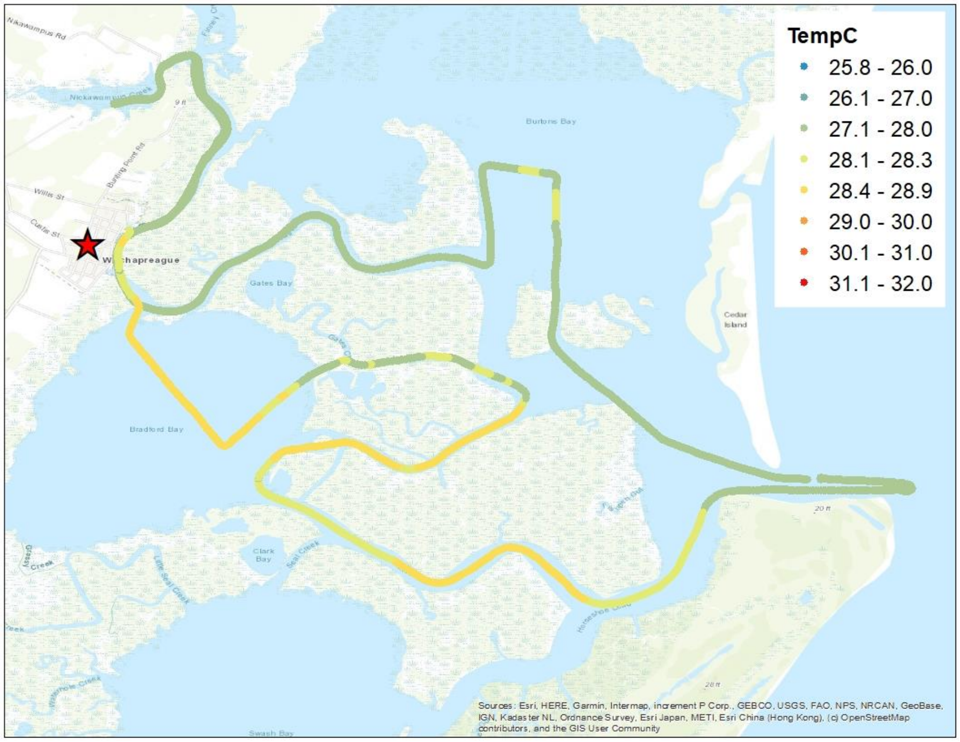
**Table 4-2**. Summary data for the 2023 Dataflow runs

| Low slack | Chlorophyll RFU | ODO mg/L | Sal psu | TAL PE RFU | TDS mg/L | Turbidity FNU | pH | Temp °C |
|---|---|---|---|---|---|---|---|---|
| **avg** | 2.53 | 5.29 | 30.27 | 8.03 | 30355 | 19.90 | 7.57 | 27.89 |
| **std** | 3.50 | 0.50 | 2.09 | 11.01 | 1897 | 1.40 | 0.11 | 0.40 |
| **min** | 0.14 | 3.81 | 21.61 | 1.57 | 22412 | 7.73 | 7.23 | 25.79 |
| **max** | 26.62 | 8.52 | 31.71 | 86.87 | 31658 | 608.61 | 7.77 | 28.86 |

| High slack | Chlorophyll RFU | ODO mg/L | Sal psu | TAL PE RFU | TDS mg/L | Turbidity FNU | pH | Temp °C |
|---|---|---|---|---|---|---|---|---|
| **avg** | 1.60 | 7.06 | 31.54 | 5.86 | 31527 | 55.96 | 7.83 | 28.65 |
| **std** | 1.18 | 0.53 | 0.46 | 3.13 | 373 | 1.74 | 0.09 | 1.68 |
| **min** | 0.25 | 5.94 | 29.36 | 1.79 | 29662 | 11.11 | 7.61 | 26.08 |
| **max** | 7.12 | 9.74 | 32.08 | 18.20 | 31969 | 481.62 | 8.03 | 32.37 |

**Figure 4-1** Data flow setup. Transom mount hydraulic ram and bilge pump (left) to send water to a YSI EXO2 Sonde with a flow cell held in a wooden bracket (upper right), cabled to an EXOGo GPS antenna and data integrator (lower right) to send georeferenced sonde data to a laptop by bluetooth.

**Low Tide**



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

**High Tide**

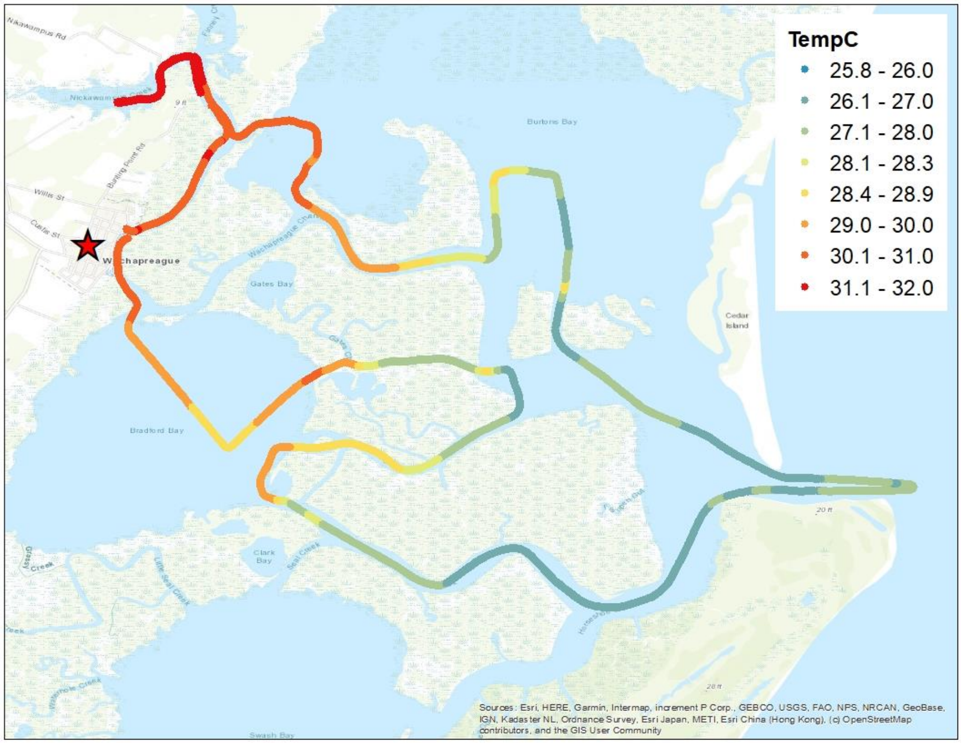


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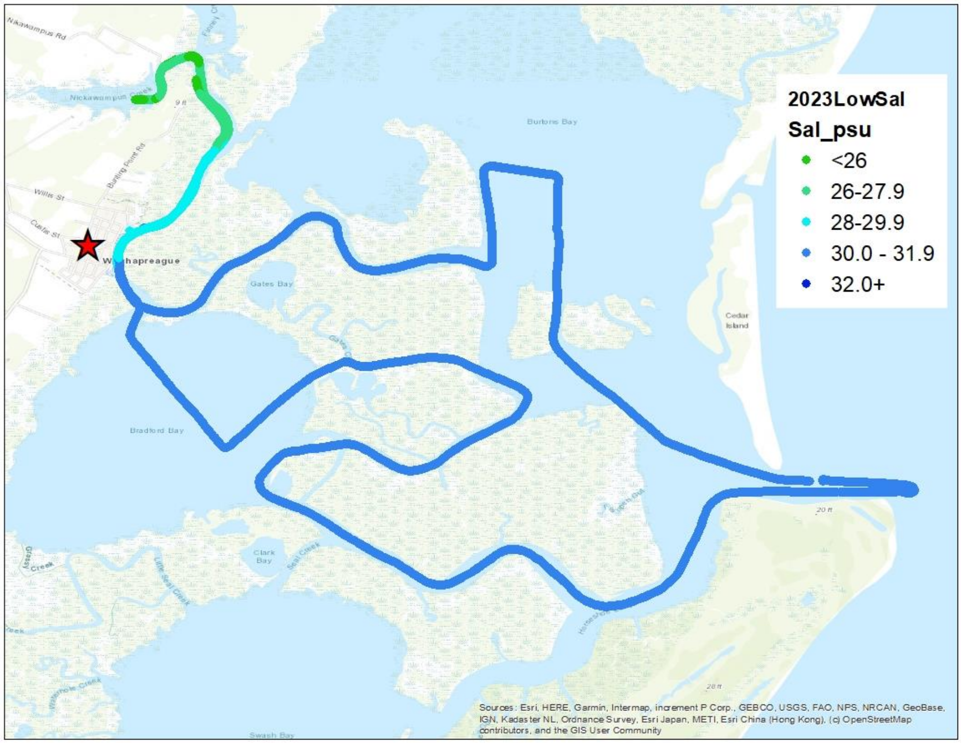
**Figure 4-2** GIS plot for water temperature (°C) during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

**Low Tide**



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

**High Tide**

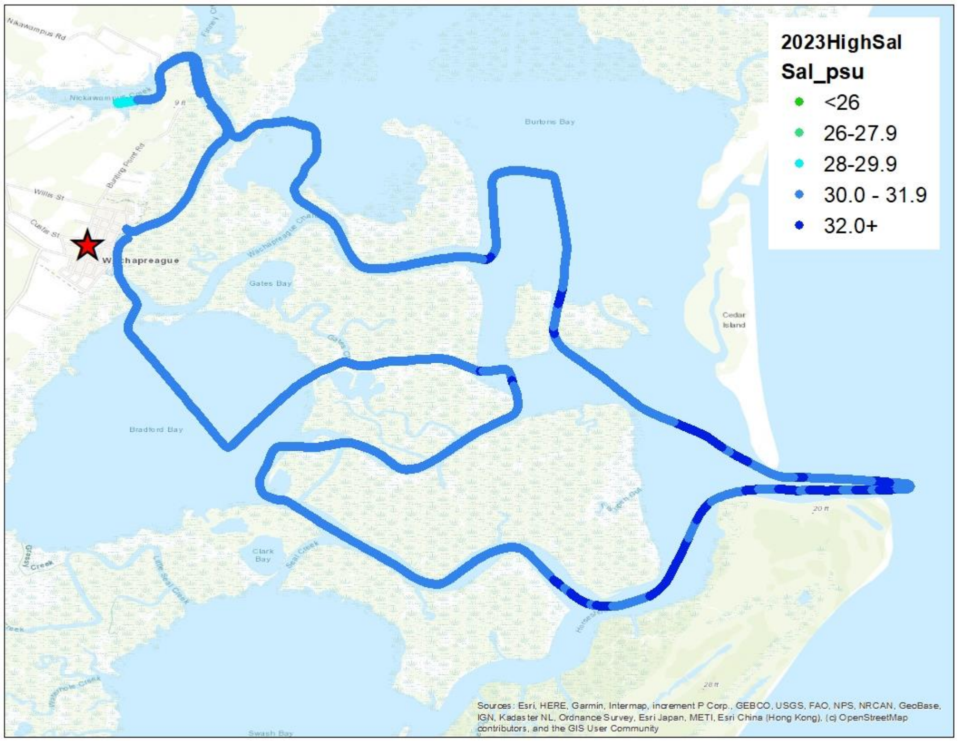


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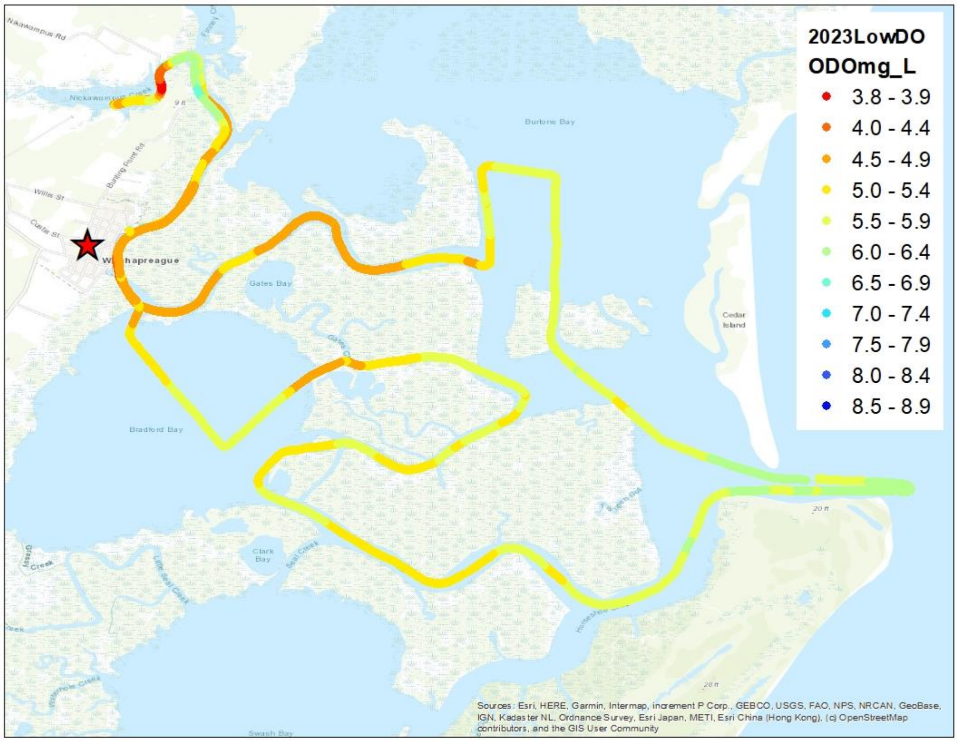
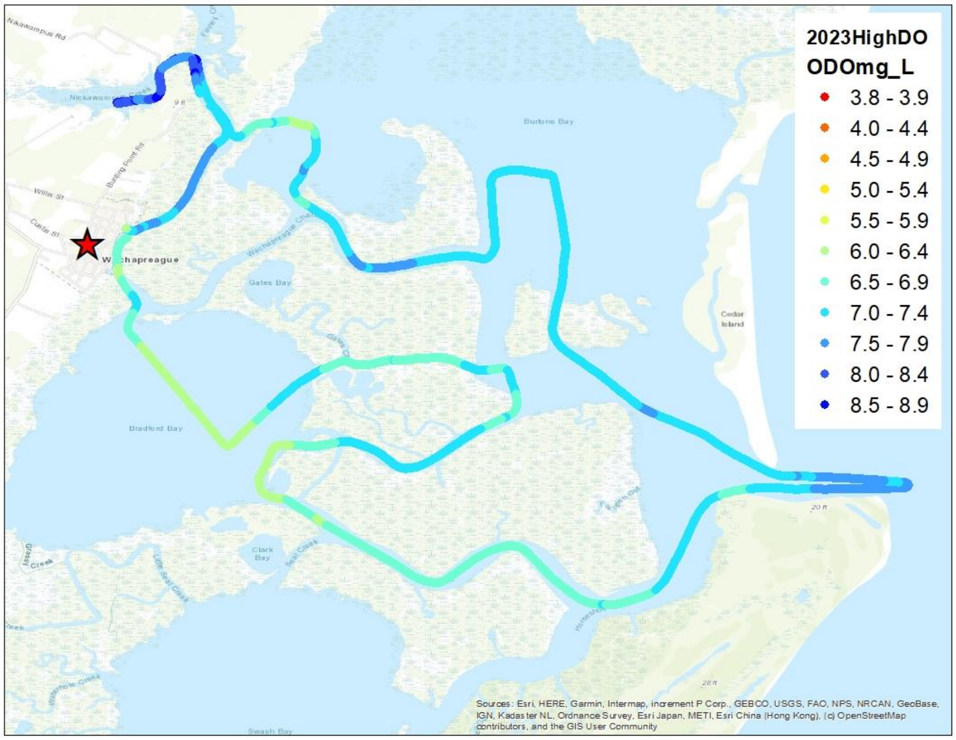
**Figure 4-3** GIS plot for salinity (psu) during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

**Low Tide**



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

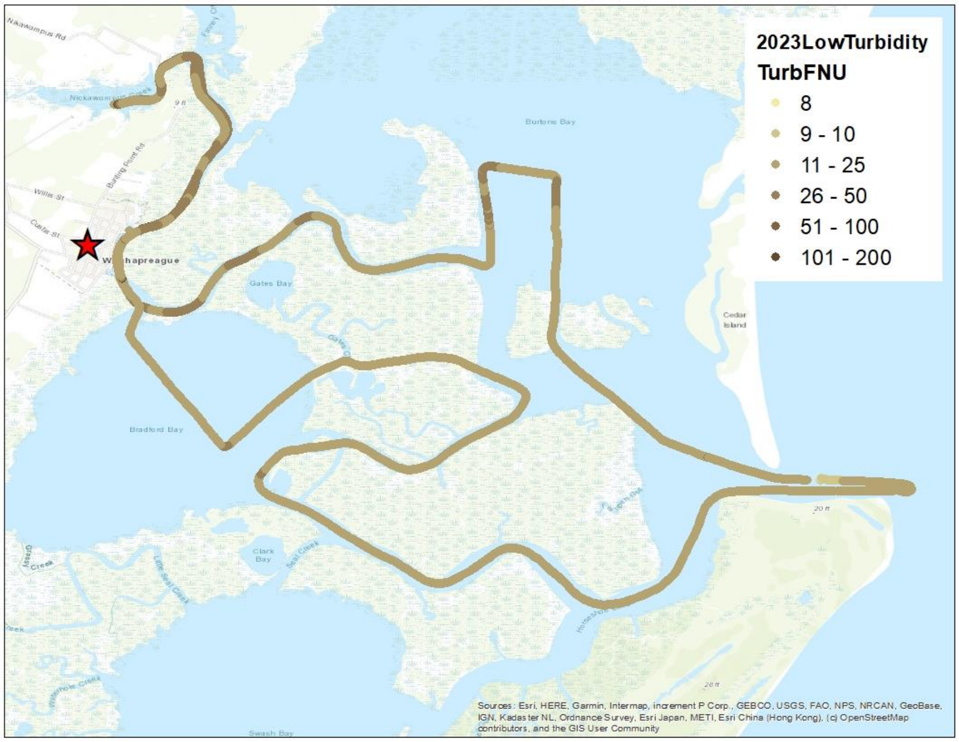
**High Tide**



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

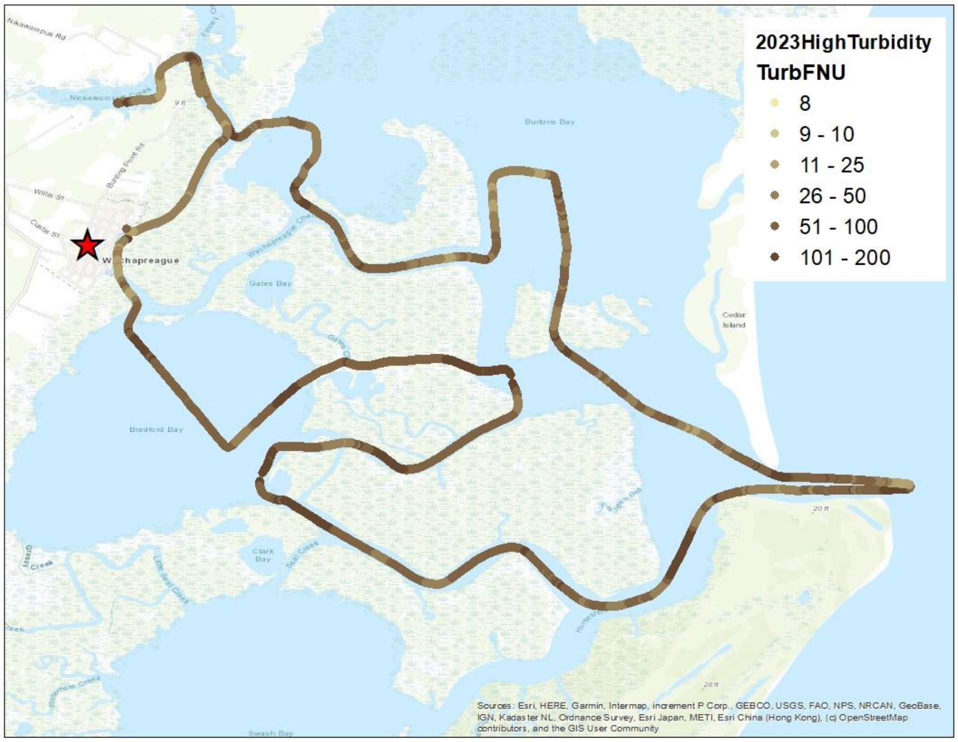
**Figure 4-4** GIS plot for dissolved oxygen (mg/L) during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

Low Tide



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

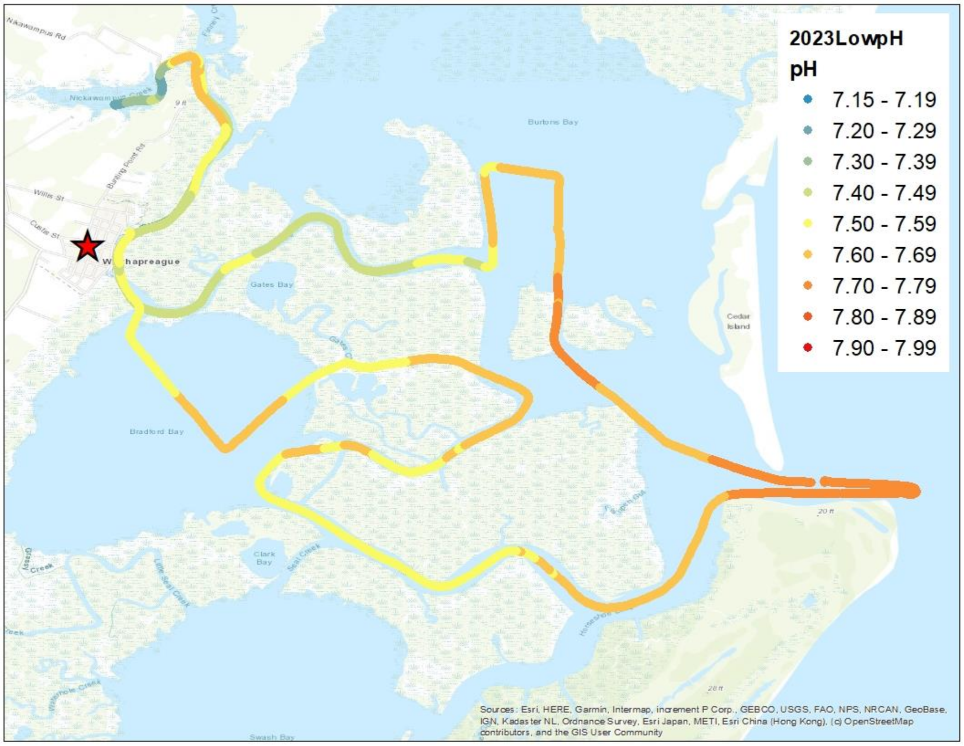
High Tide



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

**Figure 4-5** GIS plot for turbidity (NTU) during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

**Low Tide**



**High Tide**

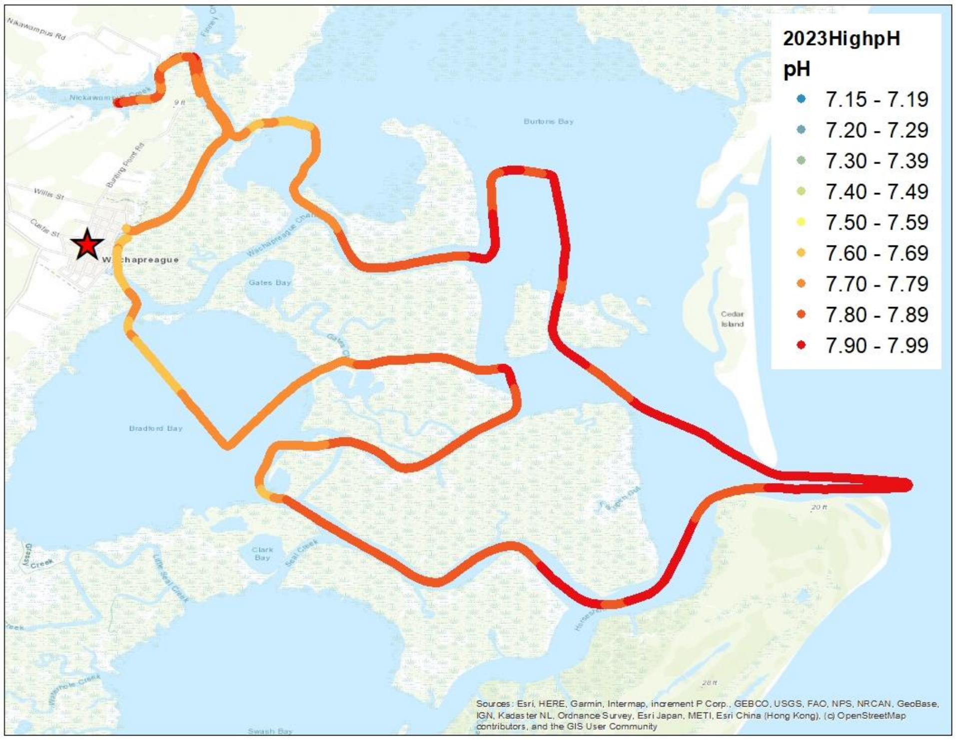
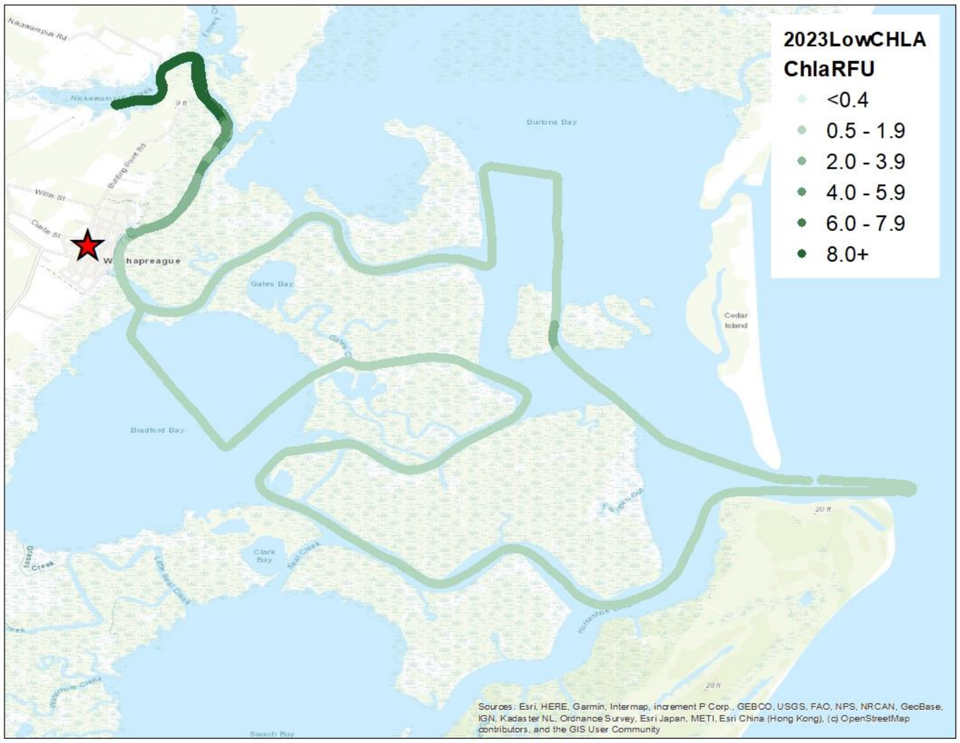


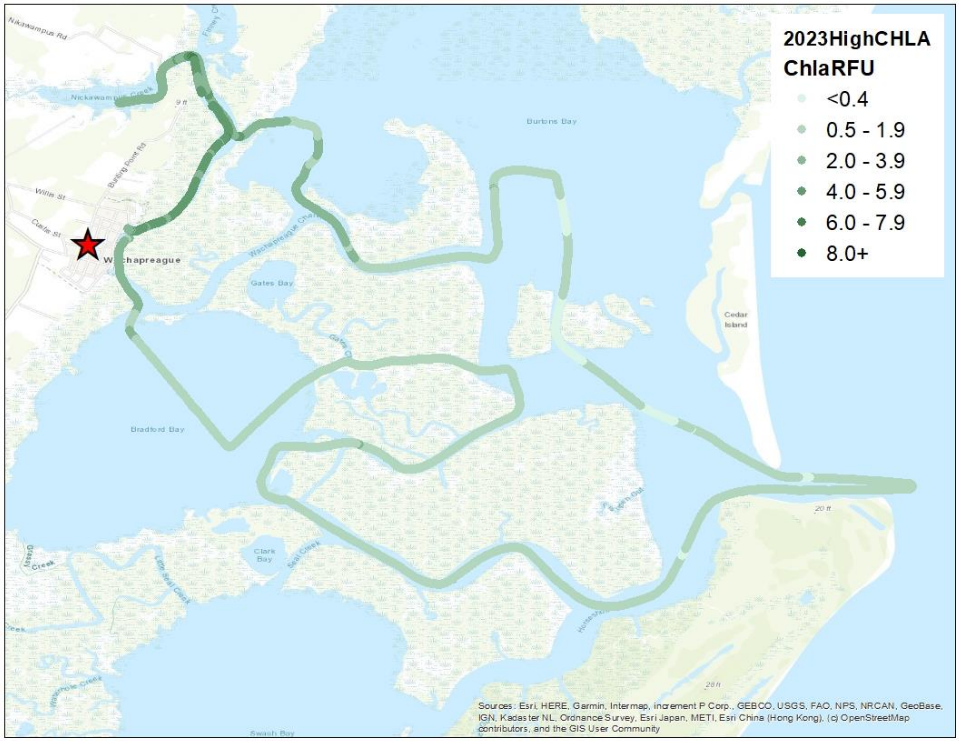
**Figure 4-6** GIS plot for pH during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

**Low Tide**



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

**High Tide**



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

**Figure 4-7** GIS plot for chlorophyll (Chla, RFU) during a ~1 hr data flow cruise centered on: (*Top*) low slack tide (low at 8:50 AM) and (*Bottom*) high slack tide (high at 3:20 PM) on 26 July 2023 near Wachapreague, VA (red star).

# Chapter 5. Sediment Characterization

*Authors*: P.G. Ross and Richard Snyder

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### 7-year sampling plan:

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | | Complete | | Complete | |

### 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 velocities/tidal flushing, and wave energy all interact to influence sediment sorting, transport, deposition, and resuspension. These sediment 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 significant carbon storage reservoir in changing global carbon dynamics.

### Study Area & Methods

We selected 27 locations to characterize the soft sediment faunal community (see Chapter 14). At each of these sites we also collected sediment samples utilizing a push-core (Fig. 5-1). These core samples were distributed in three geographic areas (Figs. 5-2) and were stratified within each area into intertidal (exposed at MLLW), shallow subtidal (>0 to ≤ 1.5 m deep at MLLW) and deep/channel edge (>1.5 to 2.5 m at MLLW) sub-habitats (Table 5-1). All samples were collected on June 15-16, 2023.

Push cores were taken to a depth of 10-15 cm. We then sub-sampled each core for surficial sediment for organic matter (SOM) and benthic chlorophyll (Chla) concentrations. Two subsamples to 1 cm deep using a 1.4 cm diameter (1.5 $cm^2$ aerial footprint) tube were collected and combined into one pre-labelled 15 ml Falcon tube for Chla analysis. The remainder of the core sample to 1 cm depth was collected for SOM analysis. Both samples were transported back to the lab on ice in dark conditions. These samples were subsequently frozen at -20° C.

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 phaeophytin was then measured after adding 50 µl HCl to acidify the sample.

**2023 Results**

Overall at grab sample sites, SOM ranged from 0.1-4.9%, with differences apparent between geographic areas and some variation in different water depth categories (Table 5-1). Mean % SOM pooled by study area suggest that Bradford Bay > Burton’s Bay > Inlet (Table 5-2). Data from all the samples visualized in GIS elucidate these macro-geographic patterns between study areas and also interesting patterns within them (Fig. 5-3). These patterns seem consistent with relative hydrographic energy distribution.

Overall, mean surficial Chla ranged from near zero to153 µg m$^{-2}$ in 2023. Chla exhibited macro geographic patterns related to water depth (light attenuation) and an inlet-to-enclosed-bay gradient (Fig. 5-4). This general pattern is consistent for multiple years with the intertidal sites and more quiescent areas having the highest surficial benthic Chla levels. It should be noted that chlorophyll data reflect the accumulated biomass in these samples and does not necessarily reflect the turnover from productivity and grazing.

**Comparison to Previous Years**

Annual differences in SOM at each of the 27 individual sites from 2018-2023 have been quite minimal (Table 5-1). The differenecs that do exist are likely due to spatial patchiness variation for that metric. Compared to 2021, only five samples exhibited greater than +/- 1 % change; 2 stations each in Bradford and Burton’s bays and one near Wachapreague Inlet (Fig. 5-5). Interestingly, all of those differences were negative. Looking at the data from 2018 to 2023 a little deeper, there is a possible trend starting, although there are only four years of data points. Although there is nothing definitive, we mention here that there may be a trend of lower surficial organic matter over time. Hints can be seen in the data pooled by study area (Table 5-2) and pooled by sub-habitat and study area (Fig. 5-6). Plotting the data from Table 5-2 shows a general downward trend with relatively high R$^2$ values (Fig. 5-7). Whether this is just natural variation in this metric or whether a real system-wide change is occurring should be further examined with subsequent data in 2025 and 2027.

## Discussion

Results for 2023 are mainly reported as basic summary data, however, several geographic patterns are apparent. Differences in SOM (Figs. 5-3) and Chla (Fig. 5-4) 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 data to date, this appears to be important to providing a broader picture of the status and, eventually, trends we see with various metrics such as those reported here (e.g. see Fig. 5-6 for SOM by study area and water depth over time).

An emerging scenario of a change in surficial organic material is certainly interesting and, if this is indeed a pattern, the cause and implications are likely complex. Collecting these surficial (top 1 cm) sediment samples is difficult to not overly disturb the sediment matrix and sampling could be a source of variation. However, we have been using the same gear, protocol and lead field personnel for all years of data reported here. We have seen substantial coastal change in the area with barrier island migration and shifting shoal/channel patterns in the vicinity of Wachapreague Inlet. Some other anecdotal changes have been seen further inland as well (Ross, pers. observation). Subsequent years of data should help resolve if changes are real. Other impacts of relatively swift barrier island and back marsh changes are starting to be quantified in ways that have potential large-scale implications for the region (e.g. organic carbon cycling [Barksdale et al. 2023]).

## 2023 Acknowledgements

We would like to thank Hunter Rippon, Oscar Melendez Vera, Emory Harned, and Edward Smith for field and lab assistance.

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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.

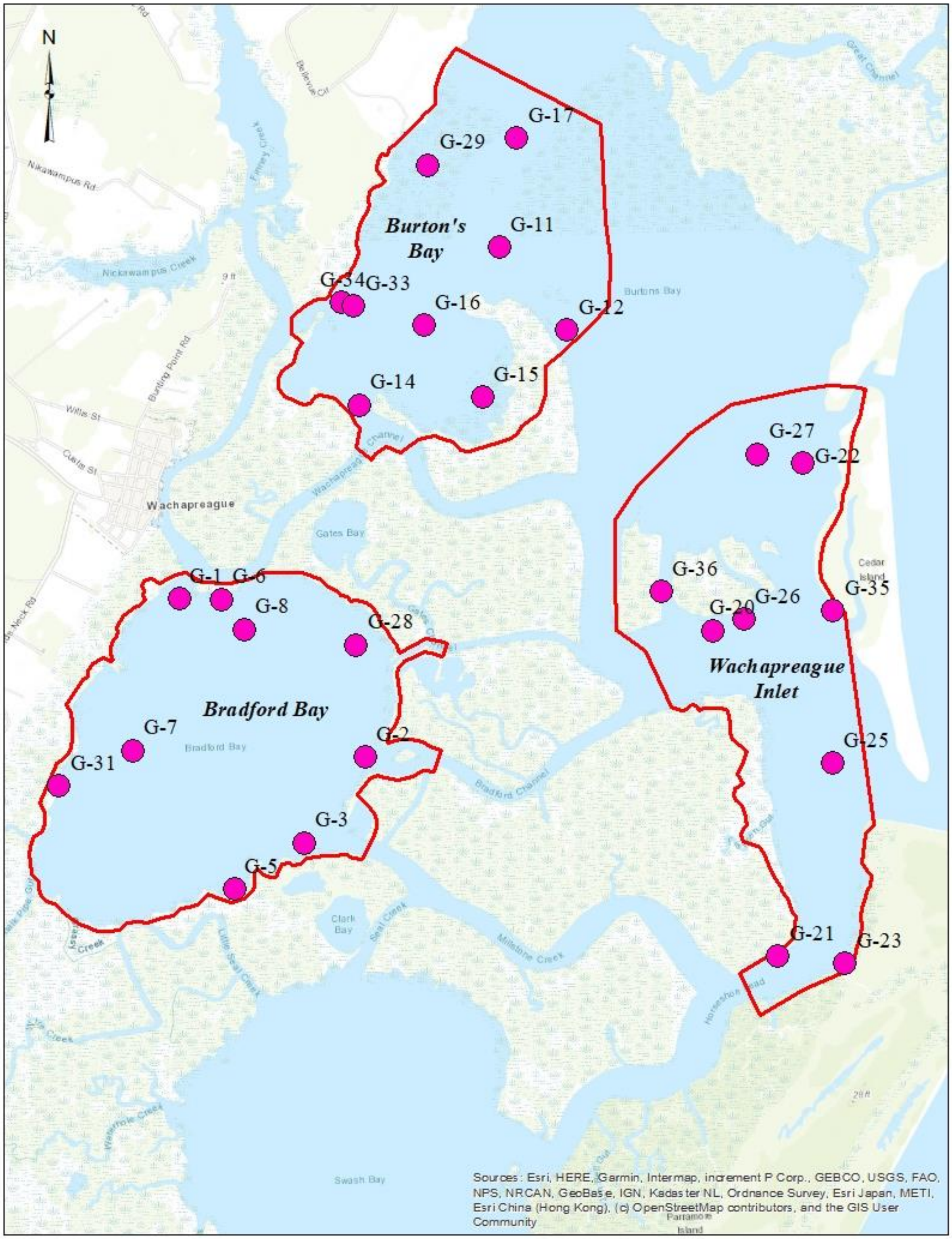
**Table 5-1**. Summary of site-specific surficial sediment organic matter (%) at 9 grab sampling sites within the three study areas that were stratified into 3 water depth categories near Wachapreague, VA during 2018, 2019, 2021, and 2023. See Figure 5-2 for a map of site locations.

| **Study Area** | **Water Depth Category** | **Site** | **2018** | **2019** | **2021** | **2023** | **Average (2018-2023)** |
|---|---|---|---|---|---|---|---|
| Bradford Bay | Intertidal | G5 | 1.9 | 4.5 | 4.0 | 3.5 | 3.5 |
| | | G6 | 3.6 | 1.2 | 2.4 | 0.5 | 1.9 |
| | | G31 | 1.8 | 2.6 | 3.2 | 3.3 | 2.7 |
| | Shallow Subtidal | G7 | 6.2 | 4.2 | 4.9 | 4.1 | 4.8 |
| | | G8 | 5.6 | 3.6 | 4.2 | 2.6 | 4.0 |
| | | G28 | 4.6 | 4.1 | 4.0 | 3.5 | 4.1 |
| | Deep | G1 | 7.2 | 5.6 | 5.1 | 4.9 | 5.7 |
| | | G2 | 2.8 | 2.4 | 1.7 | 1.7 | 2.2 |
| | | G3 | 2.6 | 2.4 | 2.7 | 1.9 | 2.4 |
| Burton's Bay | Intertidal | G14 | 4.5 | 3.1 | 3.5 | 3.8 | 3.7 |
| | | G15 | 6.7 | 6.0 | 4.9 | 4.6 | 5.5 |
| | | G33 | 0.7 | 0.6 | 0.4 | 0.6 | 0.6 |
| | Shallow Subtidal | G16 | 4.6 | 3.6 | 3.6 | 0.5 | 3.1 |
| | | G17 | 4.0 | 3.2 | 2.7 | 2.8 | 3.2 |
| | | G29 | 3.0 | 4.2 | 3.7 | 4.4 | 3.8 |
| | Deep | G11 | 3.2 | 1.7 | 2.6 | 3.0 | 2.6 |
| | | G12 | 2.1 | 1.4 | 3.0 | 1.1 | 1.9 |
| | | G34 | 1.6 | 2.0 | 0.7 | 1.0 | 1.3 |
| Wach Inlet | Intertidal | G22 | 0.6 | 0.5 | 0.6 | 0.3 | 0.5 |
| | | G23 | 0.6 | 2.5 | 0.8 | 0.5 | 1.1 |
| | | G35 | 1.8 | 1.5 | 1.1 | 1.7 | 1.5 |
| | Shallow Subtidal | G25 | 0.3 | 0.0 | 0.2 | 0.1 | 0.2 |
| | | G26 | 0.5 | 0.2 | 0.5 | 0.2 | 0.3 |
| | | G27 | 1.2 | 0.5 | 1.1 | 0.3 | 0.8 |
| | Deep | G20 | 2.6 | 0.4 | 1.1 | 0.8 | 1.2 |
| | | G21 | 5.2 | 1.7 | 1.4 | 0.4 | 2.2 |
| | | G36 | 3.3 | 3.0 | 2.5 | 0.5 | 2.3 |

**Table 5-2**. Summary of mean surficial sediment organic matter (%) at grab sampling sites overall and within 3 geographic areas near Wachapreague, VA during 2018, 2019, 2021 and 2023.

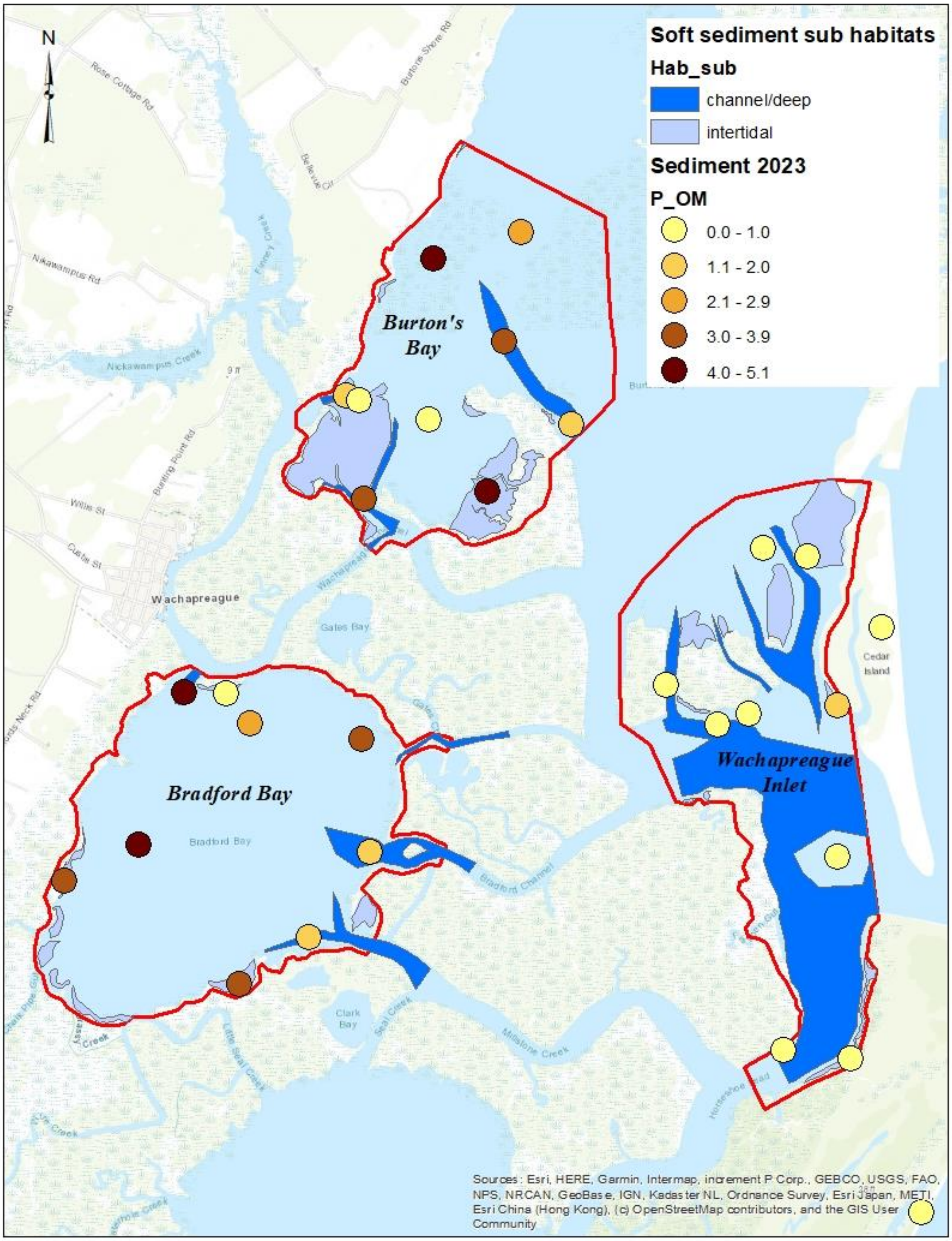
| Study Area | 2018 | 2019 | 2021 | 2023 | Average (2018-2023) |
|---|---|---|---|---|---|
| Bradford Bay | 4.0 | 3.4 | 3.6 | 2.9 | 3.5 |
| Burton's Bay | 3.4 | 2.9 | 2.8 | 2.4 | 2.9 |
| Wach. Inlet | 1.8 | 1.1 | 1.0 | 0.5 | 1.1 |

**Figure 5-1** Push corer used to collect sediment samples.



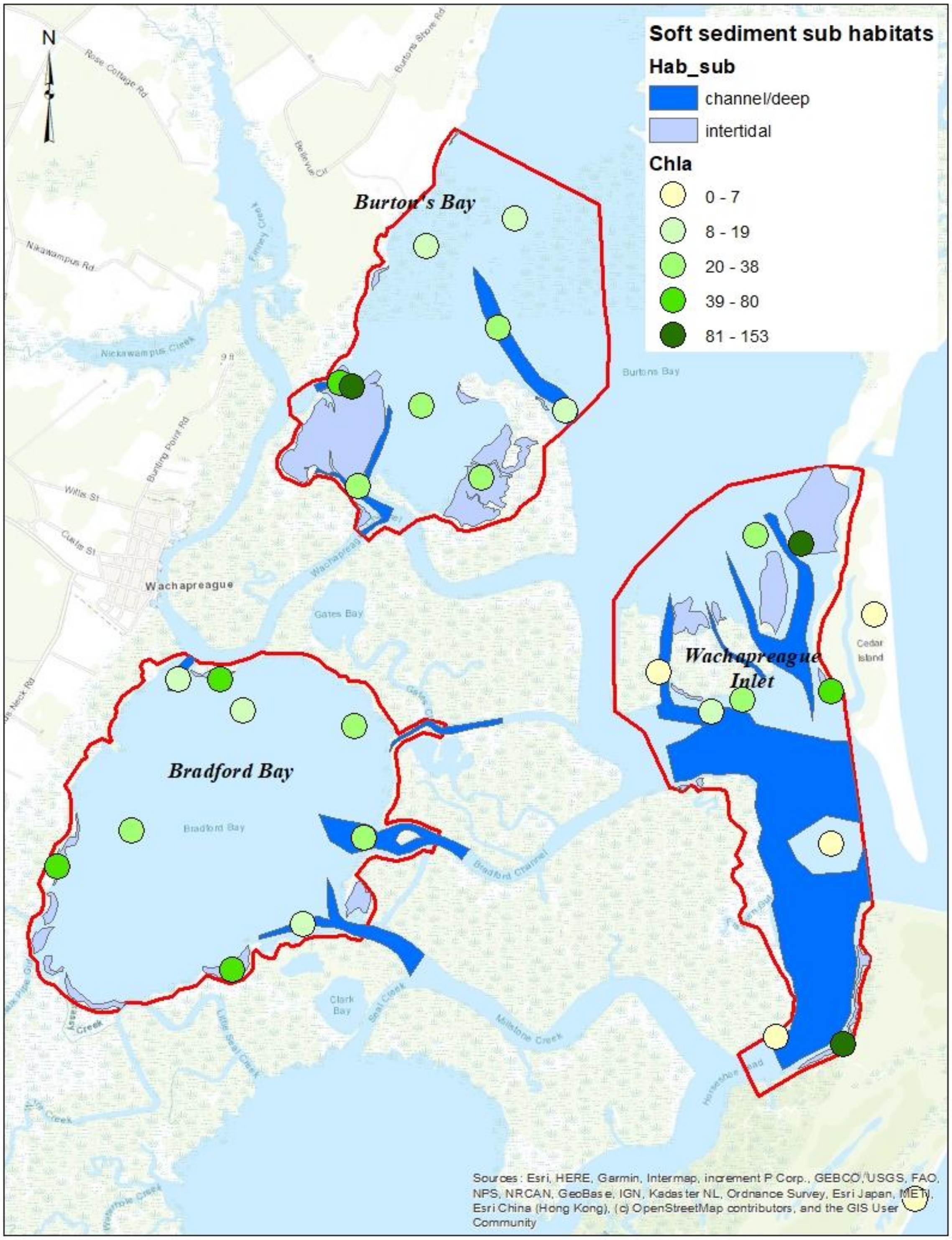
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

**Figure 5-2** Locations of 27 sites where sediment was collected near Wachapreague, VA in 2023 (red polygons denote the ESL-EMP study areas). Numbers correspond to grab sample sites in Tables 5-1.



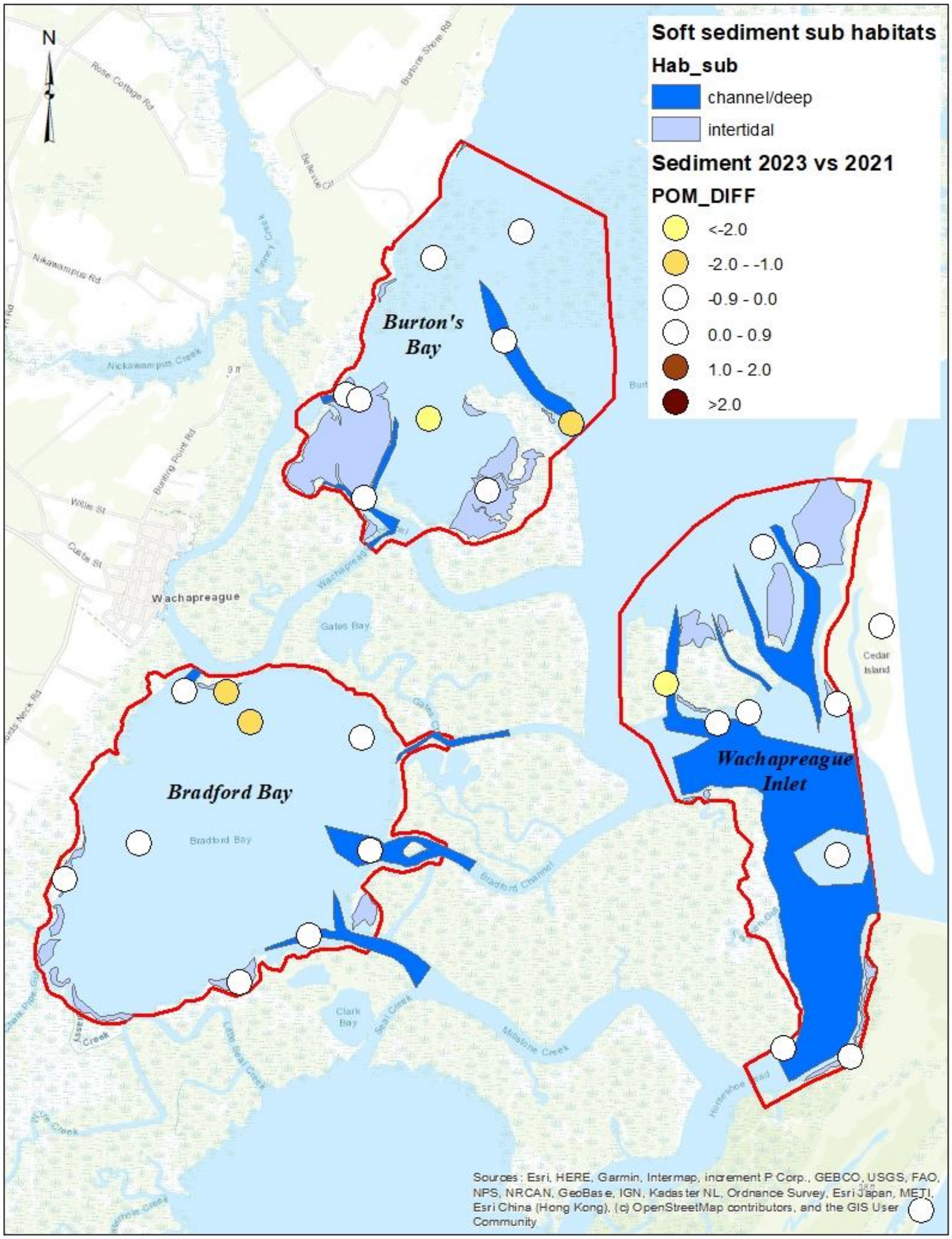
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

**Figure 5-3** Geographic visualization of surficial % sediment organic matter (top 1 cm of seabed) at 27 sites near Wachapreague, VA in 2023 (red polygons denote the ESL-EMP study areas). Water depth sub-habitat categories are visualized per the legend. Shallow subtidal areas are the light blue area of the base map.



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

**Figure 5-4** Geographic visualization of surficial (top 1 cm of seabed) chlorophyll a (µg m$^{-2}$) at 27 sites near Wachapreague, VA in 2023 (red polygons denote the ESL-EMP study areas). Water depth sub-habitat categories are visualized per the legend. Shallow subtidal areas are the light blue area of the base map.



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

**Figure 5-5** Geographic visualization of change in surficial % sediment organic matter (top 1 cm of seabed) from 2021 to 2023 at 27 sites near Wachapreague, VA in 2023 (red polygons denote the ESL-EMP study areas). Differences of +/- 1% are white and considered as “no change”. Water depth sub-habitat categories are visualized per the legend. Shallow subtidal areas are the light blue area of the base map.

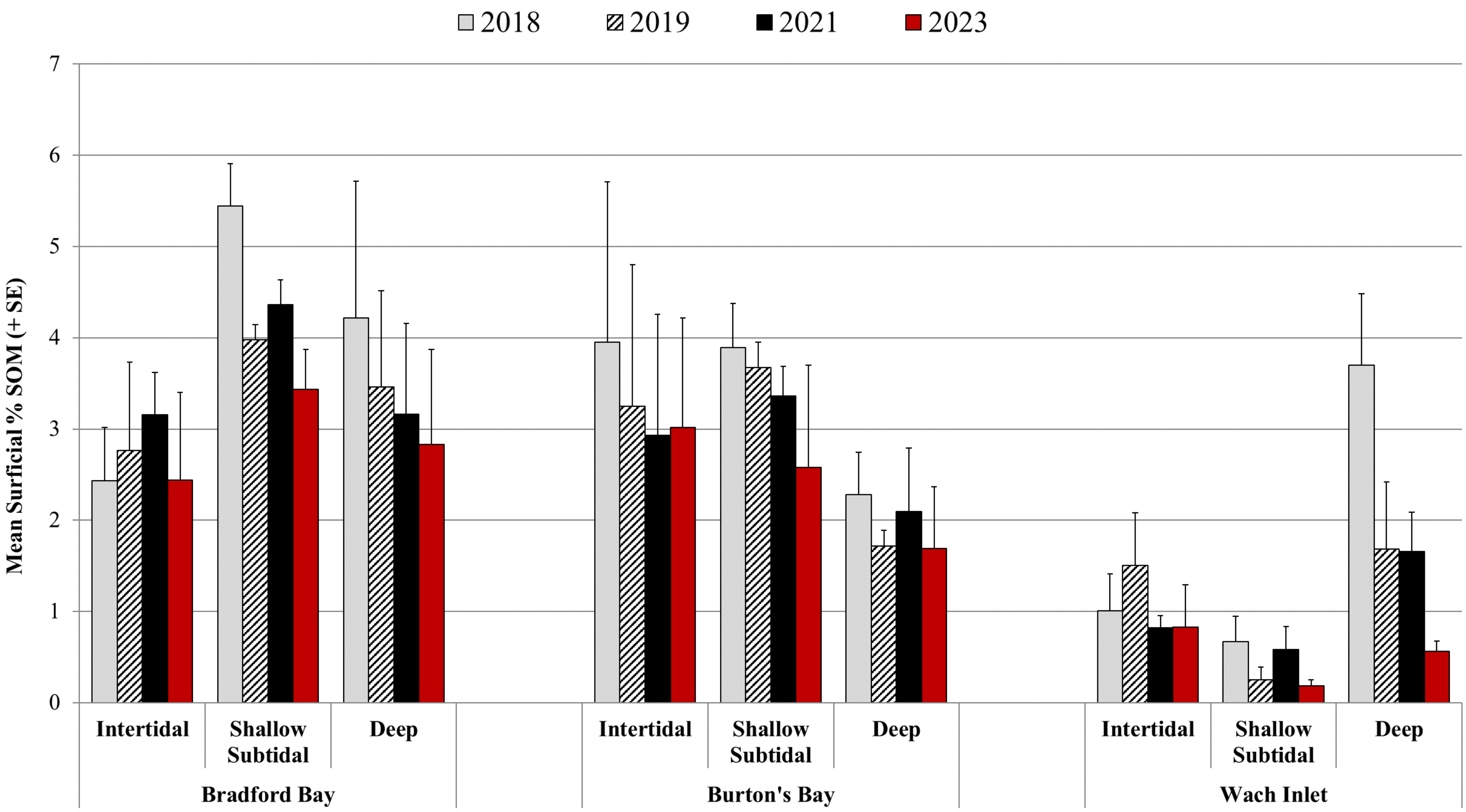


**Figure 5-6** Mean surficial % organic matter (+SE) from 2018, 2019, 2021, and 2023 for different water depth categories within 3 study areas near Wachapreague, VA.

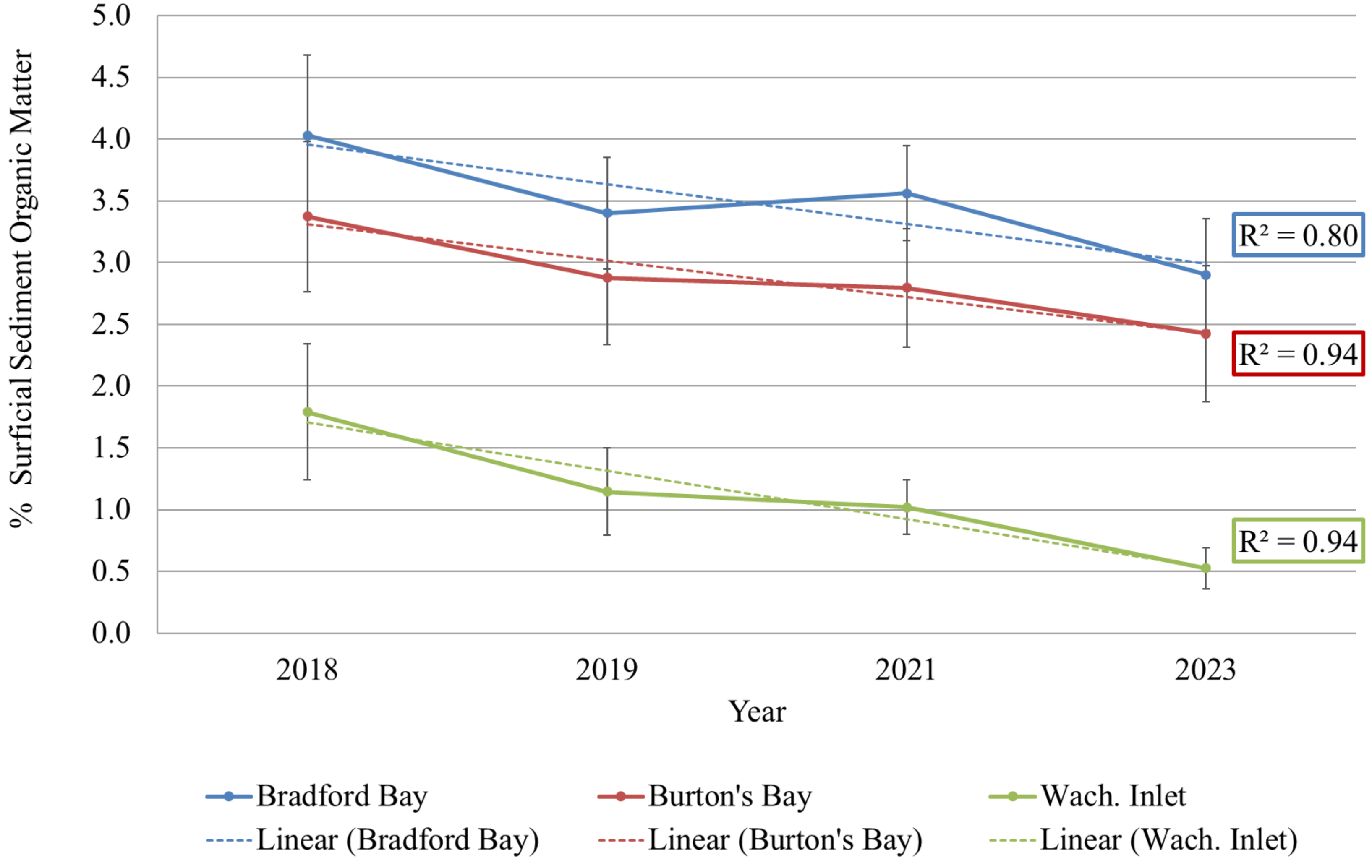


**Figure 5-6** Mean surficial % organic matter (+SE) from 2018, 2019, 2021, and 2023 for for 3 study areas near Wachapreague, VA. Dashed lines are respective linear trendlines with their resulting $R^2$ value in color coded boxes beside graphs.

# Chapter 6. Shoreline Mapping: Wachapreague Inlet

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Partial | Complete | Complete | | | |

## 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; Robbins et al., 2022). 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 at many scales, but large-scale shoreline changes are often the most broadly noticeable. This is certainly the case in the Wachapreague Inlet vicinity. The inlet itself has been historically stable and is thought to be the remains of a Susquehanna River Paleochannel (McFarland and Beach 2019), although all such areas are inherently dynamic at some level (DeAlteris and Byrne 1975). Aerial images from the Virginia Base Mapping Program (VBMP) have documented changes on 5 to 7-year intervals and the movements of Cedar Island and ebb tide delta sediments have been significant. Given the recent rapid changes, we plan to document biennial shoreline movement in the interim periods between VBMP image collection years. We have included the most recent VBMP imaging effort for this region which was 2021. In addition to providing better temporal resolution, our previous and future drone surveys will also provide data at a finer scale than what is available from the aerial/satellite remote sensing.

These geomorphological changes will impact the biodiversity and ecosystem productivity of the coastal habitats. The types of production and overall ecological energy flows of the system are directly tied to the barrier island migration and marsh shoreline loss. Eroding marsh peat on the ocean front of Cedar island releases stored marsh production to detrital pathways, while sand overwashes bury back island marshes and create tidal flats where benthic micro and macroalgae flourish. Conversion of marsh islands to open water entails a switch from marsh detrital production to grazed phytoplankton production. The distribution and abundance of grazer (direct consumption of primary production) to detrital (processing of dead autotrophic biomass) food webs directly affects distribution, abundance and productivity species described in this report.

## Study Status

Work on this parameter was not planned for 2023. We plan to update this by using Virginia Base Mapping Program imagery from early 2025. Methodology and data from 2022 can be found here: https://scholarworks.wm.edu/reports/2849/

Ross, P. G., and Snyder, R. A. (2023) Ecological Monitoring Program at VIMS ESL: Annual report 2022. VIMS Eastern Shore Laboratory Technical Report No. 11. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/pc3t-me16

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# *Section 3: Biological Features*

# Chapter 7. Biofilms

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Complete | Complete | 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 with complex interactions between components (e.g., Matz et al. 2008). The primary structural component of biofilm is a polymer matrix (slime), typically polysaccharides of microbial origin. This polymer matrix provides some buffering of short-term environmental excursions and enhances organic substrate and mineral nutrient availability to the community. The quality of aquatic biofilms is also known to mediate larval settlement for some species, as either attractant or repellant (Dobetsov and Tiffschof 2020)

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

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

Biofilm monitoring at ESL began in 2018 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. 7-1) from 5 June to 7 August 2018, 3 June to 29 July 2019, 11 June to 7 August 2020, 24 May to 5 August 2021, 14 June to 22 August 2022, and 5 June to 31 July 2023. 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. 7-2). Panels were replaced weekly for 7 days growth 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 and phaeophytin)
- elemental analysis: carbon and nitrogen content and stable isotopes ($^{13}C$ and $^{15}N$)
- DNA extraction and sequencing for community structure
- Microscopic examination

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

### Total Solids & Organic Matter

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

### Chlorophyll

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

## Results & Discussion

Summary data for 2023 and the past five years of biofilm plates are shown in Table 7-1. Overall biofilm biomass production as Chlorophyll a content was lower than the 5-year average for all stations, and less variable with the exception of Bradford Bay with a standard deviation nearly the same as the 5-year average (Table 7-1). Dry mass was consistently above the 5-year average except for the ESL pier location (Table 7-1), suggesting a greater contribution of suspended sediment to the accumulated biofilms. Stations with the lowest percent organic matter are found at the extremes of the nutrient gradient from Finney Creek out to the inlet, reflecting sediment sources from the Finney Creek drainage and turbulence associated with the inlet (Table 7-1).

Organic content of the biofilms was a fairly consistent across all samples for 2023, returning an R on a regression line of 0.91, and a slope value of 18.2% (Fig. 7-3), close to the range of 5-year average values for the stations (15.9-18.6%; Table 1). Chlorophyll content as a function of dry mass, however, displays a very different response, with an exponential decline as biofilm dray mass increases (Fig. 7-3).

Temporal trends of biofilm parameters over the course of the summer season are shown in Figures 7-4 to 7-9. Dry mass accumulation tended to increase as the summer progressed with the exception of the ESL Pier and Inlet sites (Fig. 7-4), trends that were also reflected in the organic content accumulation (Fig. 7-5). However, the percent of organic matter in these biofilms was relatively stable across sites, especially for the Inlet, Finney Creek, and ESL Pier sites (Fig. 7-6). Chlorophyll content however, followed a seasonal trend opposite of dry mass and organic matter accumulation, showing a general decrease over time for all stations (Fig. 7-7). Assuming exponential growth during the 7-day incubation period, the calculated doubling time ($T_D$) for microalgae in the biofilms was fairly consistent over time at an overall average of 1.97 days, with the exception of Finney Creek and Custis Channel sites. Finney Creek had biofilm chlorophyll doubling times that decreased over the summer, while Custis Channel had increasing $T_D$ values, indicating slower microalgae growth later in the summer at the latter site.

These biofilms samples as ecological indicators provide several unique measures of ecosystem status and trends. Microalgal growth is responsive to integrated nutrient availability, and clearly shows the gradient from Finney Creek (source) to Wachapreague Inlet samples with its oceanic influence. Long term trends in nutrients from cultural enrichment and changing land use practices will be apparent in the response of the microalgae growth. Despite the obvious nutrient gradient, the genetic diversity and community structure of prokaryotes is strikingly homogeneous across the system. Differences in eukaryotic species' community structure will require further investigation, but the information content is a rich source to mine for patterns, and will be a springboard for research proposals and future experimental work.

Visual microscopic analysis of biofilm diatom species abundance revealed and interesting relationship between tube dwelling *Navicula* sp. and *Cylindrotheca* sp, as dominant members of the biofilm communities. Peaks in abundance of *Cylindrotheca* appeared to corespondend to decreases in *Navicula* (Fig. 7-9). The reason for this intriguing pattern is as yet undefined, but suggests an interesting question for further investigation.

## Acknowledgements

We would like to thank Edward Smith, Justin Paul, and Glenn Brundage for assistance.

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**Table 7-1**. Biofilm composition averages and standard deviations (SD) for the summer monitoring period by year and by station. Chl a = chlorophyll a; Chl a TD = generation time (doubling time) for growth as Chlrophyll; Dry Wt = Dry weight; Ash-Free Dry Wt = organic content; % OM is the proportion of dry weight represented by organic matter.

| Year | Station Name | Chl a g $m^{-2}$ | Std | Chl a $T_D$ days$^{-1}$ | std | Dry wt g $m^{-2}$ | std | Ash Free Dry wt g $m^{-2}$ | std | % OM | std |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2019 | Bradford Bay | 0.268 | 0.219 | 2.71 | 2.23 | 2.675 | 1.522 | 0.461 | 0.276 | 16.90 | 2.80 |
| 2019 | Custis Channel | 0.227 | 0.231 | 1.48 | 1.98 | 3.160 | 2.862 | 0.459 | 0.302 | 16.50 | 4.20 |
| 2019 | ESL Pier | 0.213 | 0.21 | 2.14 | 0.89 | 5.680 | 4.192 | 0.836 | 0.622 | 17.50 | 5.60 |
| 2019 | Finney/Nick | 0.328 | 0.323 | 2.94 | 3.31 | 2.996 | 2.377 | 0.522 | 0.434 | 14.70 | 1.60 |
| 2019 | Inlet | 0.309 | 0.368 | 1.96 | 1.51 | 2.134 | 1.367 | 0.326 | 0.185 | 15.60 | 2.30 |
| | | | | | | | | | | | |
| 2020 | Bradford Bay | 0.218 | 0.087 | 1.70 | 0.44 | 2.216 | 1.772 | 0.319 | 0.266 | 14.20 | 1.40 |
| 2020 | Custis Channel | 0.253 | 0.119 | 1.59 | 0.29 | 1.433 | 0.771 | 0.162 | 0.086 | 12.80 | 2.20 |
| 2020 | ESL Pier | 0.299 | 0.13 | 1.64 | 0.67 | 7.321 | 5.004 | 0.968 | 0.576 | 12.30 | 4.50 |
| 2020 | Finney/Nick | 0.219 | 0.165 | 1.91 | 0.64 | 2.670 | 1.746 | 0.346 | 0.250 | 14.00 | 1.90 |
| 2020 | Inlet | 0.398 | 0.163 | 1.36 | 0.17 | 1.299 | 1.153 | 0.147 | 0.132 | 11.00 | 3.30 |
| | | | | | | | | | | | |
| 2021 | Bradford Bay | 0.595 | 0.317 | 1.32 | 0.41 | 1.857 | 1.086 | 1.864 | 1.511 | 16.85 | 6.88 |
| 2021 | Custis Channel | 0.885 | 0.709 | 1.61 | 1.60 | 2.350 | 1.754 | 1.932 | 1.457 | 22.21 | 11.73 |
| 2021 | ESL Pier | 0.562 | 0.531 | 1.49 | 0.54 | 1.347 | 1.066 | 1.150 | 0.965 | 22.11 | 5.90 |
| 2021 | Finney/Nick | 0.771 | 0.445 | 1.48 | 0.12 | 5.284 | 3.981 | 4.100 | 3.338 | 21.85 | 19.01 |
| 2021 | Inlet | 0.401 | 0.15 | 1.35 | 0.12 | 1.257 | 1.257 | 1.168 | 1.168 | 16.40 | 8.94 |
| | | | | | | | | | | | |
| 2022 | Bradford Bay | 0.204 | 0.253 | 2.03 | 12.01 | 1.629 | 1.278 | 0.287 | 0.170 | 19.48 | 3.98 |
| 2022 | Custis Channel | 0.211 | 0.246 | 2.02 | 0.59 | 3.528 | 2.232 | 0.558 | 0.302 | 16.52 | 2.44 |
| 2022 | ESL Pier | 0.615 | 0.214 | 1.20 | 0.11 | 0.617 | 0.282 | 0.896 | 0.037 | 20.38 | 2.85 |
| 2022 | Finney/Nick | 0.11 | 0.179 | 3.50 | 1.39 | 3.871 | 1.343 | 0.626 | 0.169 | 16.70 | 3.10 |
| 2022 | Inlet | 0.358 | 0.192 | 1.49 | 0.37 | 1.183 | 1.183 | 0.189 | 0.145 | 19.07 | 19.07 |
| | | | | | | | | | | | |
| 2023 | Bradford Bay | 0.231 | 0.245 | 1.77 | 0.34 | 2.744 | 2.994 | 0.685 | 1.248 | 21.89 | 9.94 |
| 2023 | Custis Channel | 0.171 | 0.118 | 2.09 | 0.91 | 3.763 | 3.982 | 0.756 | 0.800 | 20.05 | 6.48 |
| 2023 | ESL Pier | 0.200 | 0.202 | 2.02 | 0.59 | 1.297 | 0.761 | 0.131 | 0.290 | 20.76 | 4.33 |
| 2023 | Finney/Nick | 0.123 | 0.091 | 2.83 | 1.98 | 6.812 | 6.915 | 1.134 | 1.052 | 16.45 | 4.77 |
| 2023 | Inlet | 0.281 | 0.145 | 1.54 | 0.25 | 1.719 | 1.311 | 0.285 | 0.215 | 17.50 | 2.56 |

**Multi-year Averages**

| Station Name | Chl a g $m^{-2}$ | Std | Chl a $T_D$ days$^{-1}$ | std | Dry wt g $m^{-2}$ | std | Ash Free Dry wt g $m_{-2}$ | std | % OM | std |
|---|---|---|---|---|---|---|---|---|---|---|
| Bradford Bay | 0.303 | 0.224 | 1.903 | 3.087 | 2.224 | 1.730 | 0.723 | 0.694 | 17.865 | 5.000 |
| Custis Channel | 0.349 | 0.285 | 1.760 | 1.074 | 2.847 | 2.320 | 0.773 | 0.589 | 17.616 | 5.410 |
| ESL Pier | 0.378 | 0.257 | 1.696 | 0.560 | 3.253 | 2.261 | 0.796 | 0.498 | 18.610 | 4.637 |
| Finney/Nick | 0.310 | 0.241 | 2.531 | 1.489 | 4.327 | 3.272 | 1.346 | 1.049 | 16.738 | 6.077 |
| Inlet | 0.349 | 0.204 | 1.540 | 0.485 | 1.518 | 1.254 | 0.423 | 0.369 | 15.915 | 7.234 |

**Figure 7-1** Locations of 5 biofilm monitoring sites near Wachapreague, VA for 2023 (red polygons denote the ESL-EMP study areas).

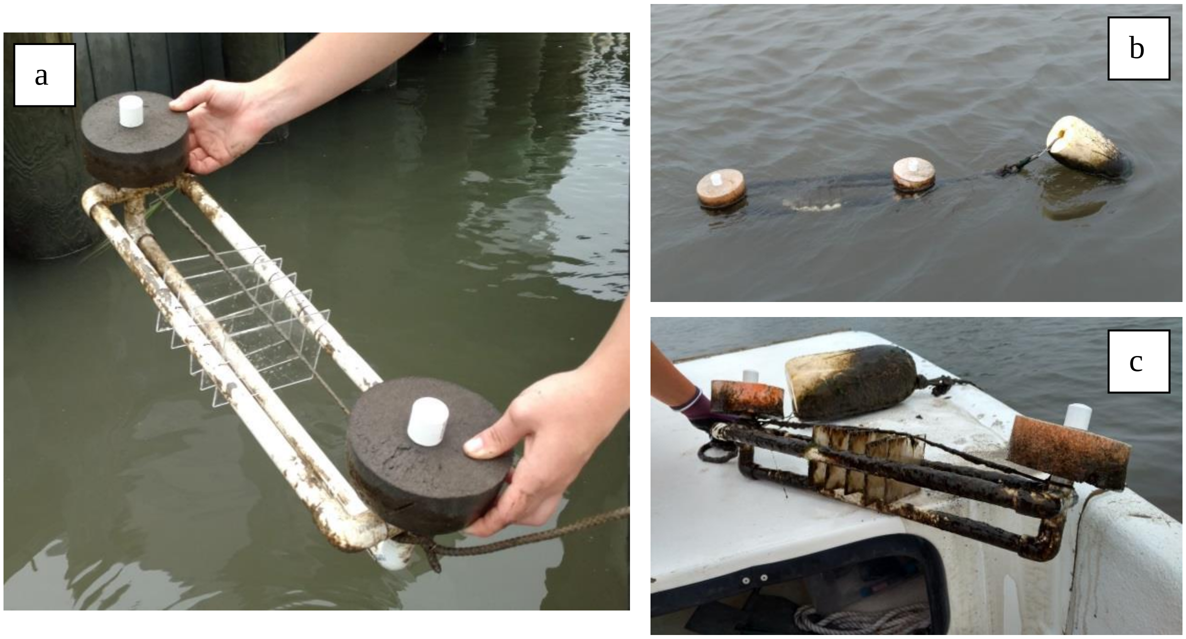
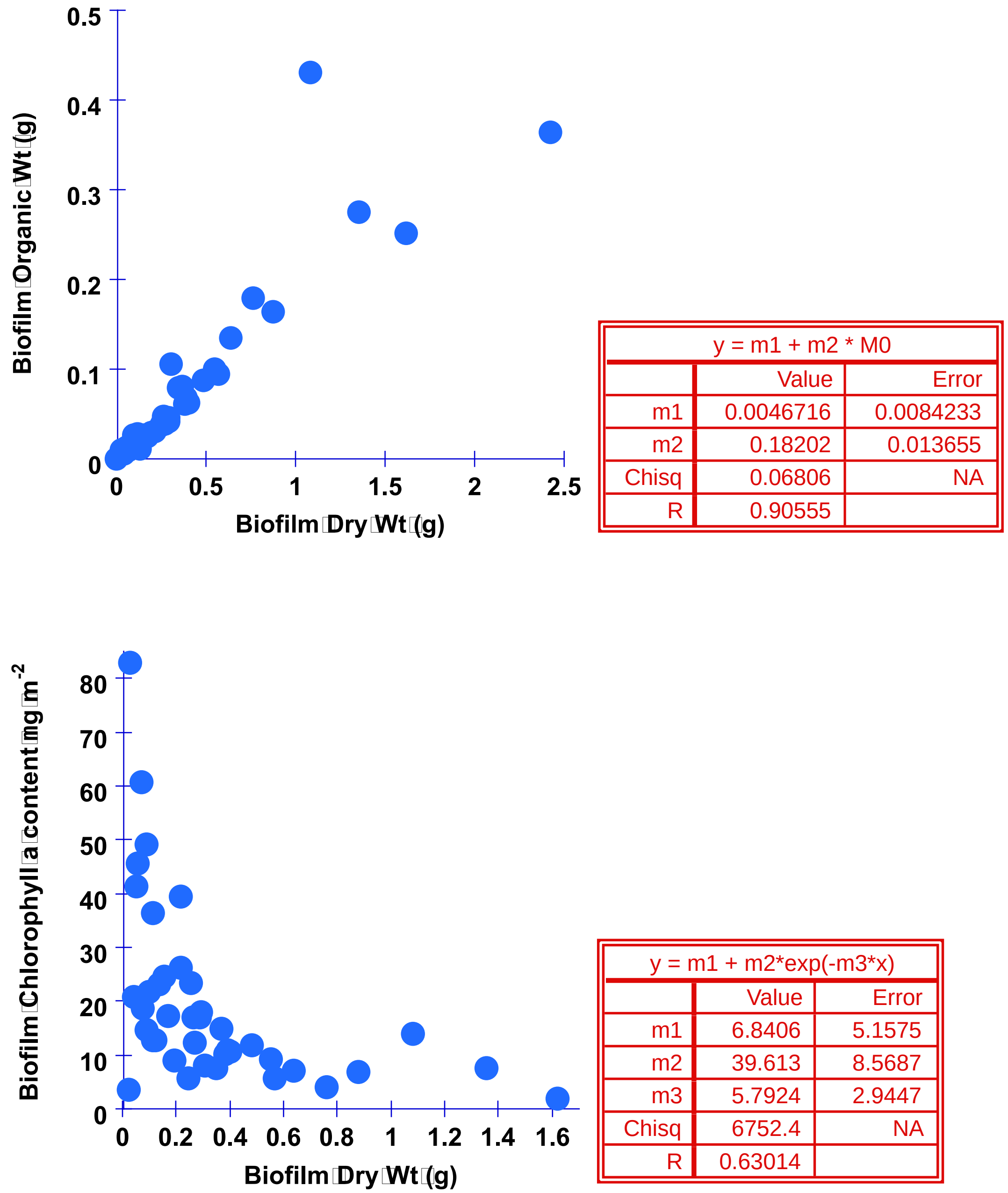


**Figure 7-2** Biofilm array a) before, b) during and c) after deployment.



y = m1 + m2 * M0

| | Value | Error |
|---|---|---|
| m1 | 0.0046716 | 0.0084233 |
| m2 | 0.18202 | 0.013655 |
| Chisq | 0.06806 | NA |
| R | 0.90555 | |

y = m1 + m2*exp(-m3*x)

| | Value | Error |
|---|---|---|
| m1 | 6.8406 | 5.1575 |
| m2 | 39.613 | 8.5687 |
| m3 | 5.7924 | 2.9447 |
| Chisq | 6752.4 | NA |
| R | 0.63014 | |

**Figure 7-3** Overall assessment of organic content (top) and Chlorophyll content (bottom) as a function of biofilm dry weight. The organic fraction was a fairly consistent proportion (18%) of dry mass across all samples (R = 0.91). The Chlorophyll fraction was most high in biofilms of low total mass, decreasing precipitously with increasing dry mass, with an exponential function returning an R of 0.63.

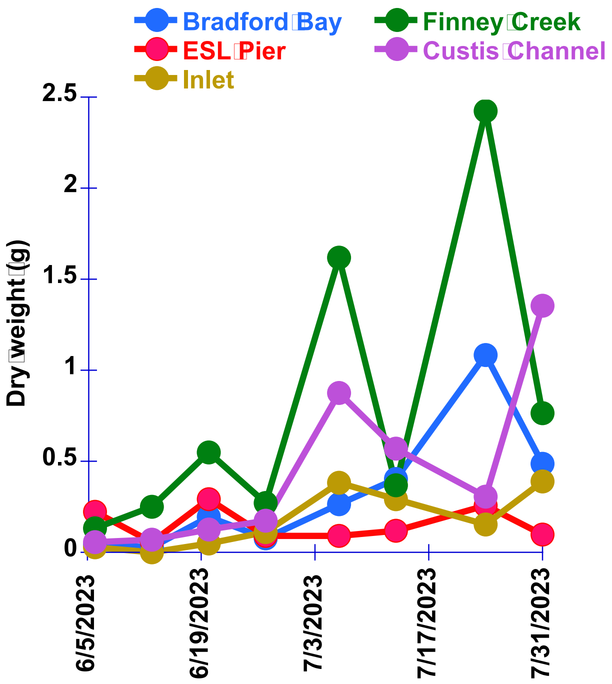


**Figure 7-4** Spatial and temporal dynamics of total biofilm mass as measured by dried weight for biofilms grown at the five stations off Wachapreague, VA during June-August 2023.

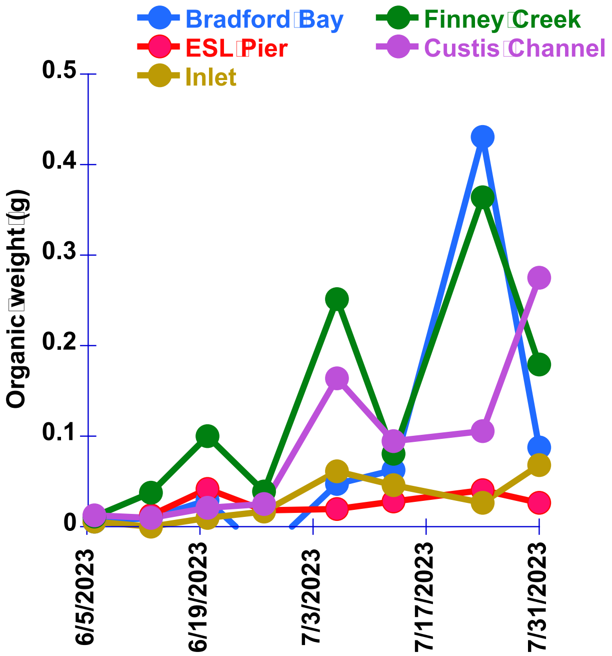


**Figure 7-5** Spatial and temporal dynamics of organic mass as measured by loss on ignition of dried biofilm samples grown at the five stations off Wachapreague, VA during June-August 2023.

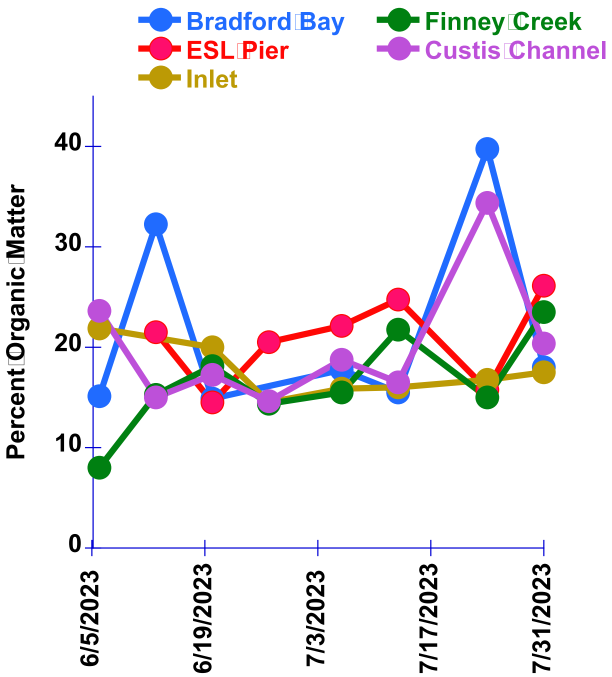


**Figure 7-6** Spatial and temporal dynamics of the precent of organic in dry mass as measured by loss on ignition of dried biofilm samples grown at the five stations off Wachapreague, VA during June-August 2023.

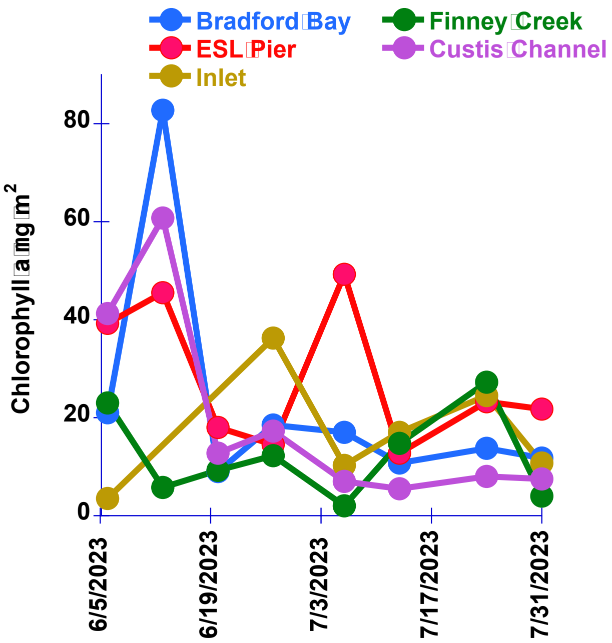


**Figure 7-7** Spatial and temporal dynamics of the chlorophyll content of biofilm samples grown at the five stations off Wachapreague, VA during June-August 2023.

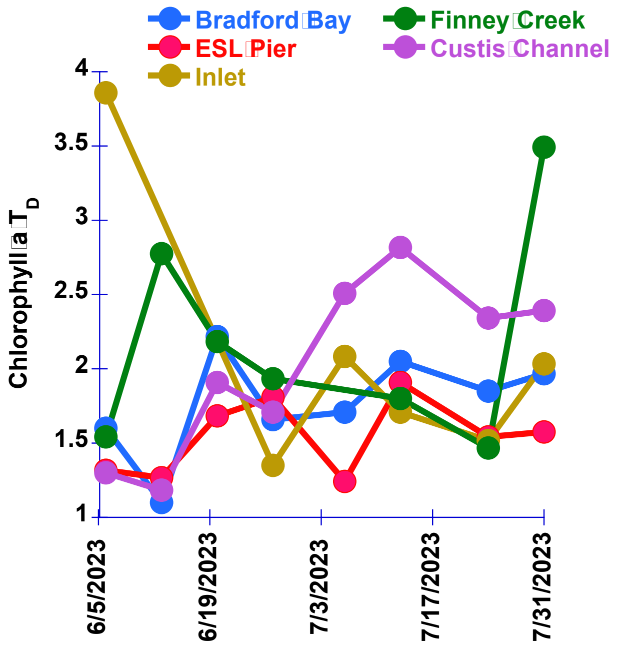


**Figure 7-8** Spatial and temporal dynamics of the doubling time (growth rate) of biofilms as measured by chlorophyl content of 7-day biofilm samples grown at the five stations off Wachapreague, VA during June-August 2023.

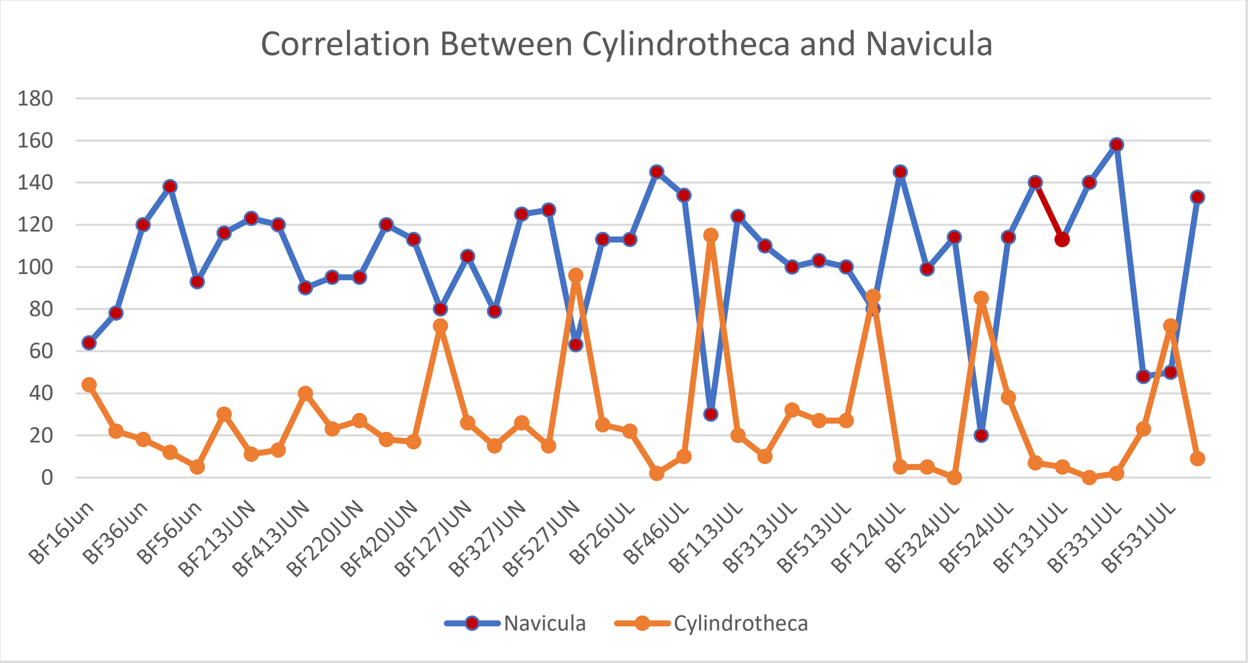


**Figure 7-9** An apparent reciprocal abundance of two dominant diatom species in biofilm samples grown at the five stations off Wachapreague, VA during June-August 2023.

# Chapter 8. Macroalgae: Intertidal Mapping

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Partial | Partial | Partial | Complete | Complete | Complete | Planned |

## Introduction

Intertidal mudflats are highly productive ecosystems, typically dominated by benthic microalgae, invertebrates, and transient fish and birds. Our knowledge of the *macroalgal* (i.e., seaweed) component in these ecosystems is both regionally and taxonomically limited. Largely, this is due to a lack of phycological history in soft sediment environments (Zaneveld and Barnes 1965, Krueger-Hadfield et al. 2017a), which in turn is due to the lack of hard substratum – a requirement for settlement and germination of macroalgal spores.

Krueger-Hadfield and Ross (2022) reviewed the state of our understanding of the macroalgal diversity along the Virginian coast. The bays and lagoons along the Delmarva Peninsula are underappreciated in their algal richness. Many macroalgal species persist as free-floating thalli or as mats (Norton and Mathieson 1983), though there is a small fraction that can be found fixed (*sensu* Krueger-Hadfield et al. 2018) to hard substratum (e.g., shells) via holdfasts. Free-living algae began their lives fixed via a holdfast to hard substratum before becoming detached (see discussion of terms in Krueger-Hadfield et al. 2023). We know very little about how these free-floating populations arise, the connectivity between fixed and free-floating thalli, why free-floating populations show reduced fertility, or why they often take on different morphologies than their fixed counterparts (Norton and Mathieson 1983).

The soft sediment habitats of the Delmarva have changed over the last 100 years with the invasion of *Gracilaria vermiculophylla*. This alga was likely present in the mid-Atlantic long before what is reported in the literature (Krueger-Hadfield et al. 2017b) and now can reach up to 100% cover and fundamentally alter both grazer and detrital pathways (McGlathery et al. 2001, Gulbransen and McGlathery 2013, Besterman and Pace 2018). Though dominated by *G. vermiculophylla,* qualitatively, we noticed strong seasonal and interannual fluctuations in biomass at the Upper Haul Over near Wachapreague – a site we have monitored intermittently since 2014 (Fig. 8-1, Krueger-Hadfield et al. 2016, 2017b, *unpublished data*, Krueger-Hadfield and Ross 2022). At the Upper Haul Over, we have only found *G. vermiculophylla* since 2014 and indeed throughout Burton's Bay (>600 gracilarioid thalli identified to species).

Here, we continue the drone surveys and optimization of remote sensing technologies to understand the distribution and abundance of *G. vermiculophylla* (Krueger-Hadfield and Ross 2022). We combined field-collected biomass during on-going phenology surveys (Krueger-Hadfield et al., *unpublished data*) with drone surveys.

## Study Area & Methods

To document interannual and seasonal patterns of *G. vermiculophylla* biomass, we mapped an intertidal mudflat area near Wachapreague, VA (37.61968, -75.66942; Fig. 8-1) using drone-based remote sensing. We gathered high resolution imagery of the study area using a DJI Phantom 4 quadcopter with multispectral cameras. (Fig. 8-2). Drone collected images were gathered at low tide at 40 m altitude and geotagged with the on-board GPS. Survey results in this report were monthly from March-August, October, and December 2023. Details of survey specifications can be found in Table 8-1.

Georeferenced images were combined into an orthomosaic using Pix4D software and then brought into ArcGIS (ESRI, 2021). Normalized Difference Vegetation Index (NDVI) was used to delineate algae and a distribution map was then derived from this data based on these pixel values using a highly supervised methodology.

Krueger-Hadfield and Ross (2022) correlated the percent cover to algal biomass (measured as wet mass) from five 1m$^2$ quadrats in November 2021. Independent of aerial surveys, algal biomass was collected during the July 2022 sample period as well as in October and December 2022 and reported in Krueger-Hadfield and Ross (2022).

## 2023 Results & Discussion

### Drone Surveys

Drone survey imagery covered ~4.3 hectares of intertidal mudflat that included our core defined study area (1.8 hectares). Qualitatively, macroalgae seen in visible imagery can be discerned in near-infrared imagery. Obvious seasonal changes in macroalgal cover were noted in the field and can be qualitatively seen in visible and near-infrared images from the different survey periods (Fig. 8-3). Our results suggest roughly the highest coverage in Winter/Spring, with very little coverage by July.

We were able to develop NVDI maps from the near-infrared images (e.g., see Fig. 8-4). Qualitative comparisons of these products between survey periods suggested useful quantitative comparisons may be possible. Using highly supervised NDVI analysis, we determined percent macroalgal cover for each survey which ranged from 5.4-20.5% for 2023 surveys (Fig. 8-5).

### Estimated Macroalgal Biomass

Based on some initial data relating aerial image derived NDVI analysis to biomass (see Chapter 8 in Ross and Snyder 2022), we used quadrat sample data that were deployed during November 2021 surveying to develop a relationship between macroalgal % cover and wet biomass (Table 8-2 and Fig. 8-6). There was a strong positive linear relationship ($R^2=0.89$; $p=0.013$) between these metrics (Fig. 8-7) that resulted in the following equation:

$$\textit{Wet Biomass Density}\ (g/m^2) = 12.2 * \textit{\% Cover} - 3.2$$

We used this linear equation to estimate wet biomass density based on aerial imagery, which ranged from 62-247 g $m^{-2}$ for 2023 surveys (Fig. 8-8).

## Comparison to previous years

Aerial surveys (mostly standardized to those in 2023) were conducted during 2020-2022. When combined with 2023 data, these previous data suggested that macroalgae abundance on the studied mudflat exhibits both seasonal and interannual patterns (Fig. 8-9). For example, coverage during 2021-2022 was generally higher than 2023 for most months that were sampled during both periods. Additionally, mid-summer (especially July surveys) consistently exhibit lower macroalgal abundance than spring, fall, and winter. This seasonality appears to be more accentuated in higher coverage years (i.e., 2021-2022) than in lower coverage years (i.e., 2023; Fig. 8-9)

## 2023 Acknowledgements

We would like to thank Richard Snyder and Sean Fate for field and lab assistance. Additional funding was provided by start-up funds from the College of Arts and Sciences at the University of Alabama at Birmingham and the National Science Foundation CAREER Award (DEB-2141971).

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**Table 8-1**. Information for macroalgae drone surveys of a mudflat near Wachapreague, VA reported in this document.

| Year | Month | Drone | Imagery Wavelength Category(ies) | Altitude (m) | Software Used for NDVI | Ground Quads |
|---|---|---|---|---|---|---|
| 2021 | Nov | Matrice 100 | NIR | 40 | ArcMap | yes |
| 2022 | Jan | Phantom 4 | Multispectral | 40 | Pix4D | - |
| 2022 | Apr | Phantom 4 | Multispectral | 40 | Pix4D | - |
| 2022 | June | Phantom 4 | Multispectral | 40 | Pix4D | - |
| 2022 | July | Phantom 4 | Multispectral | 40 | Pix4D | - |
| 2022 | Aug | Matrice 100 | NIR & VIS | 40 | ArcMap | - |
| 2023 | All | Phantom 4 | Multispectral | 40 | Pix4D | - |

**Table 8-2**. Wet weight (g) of macroalgae (mainly *Gracilaria vermiculophylla* and *Ulva* spp.) collected in 1m$^2$ quadrat samples on a mudflat during November 2021 near Wachapreague, VA.

| Quad # | Total Wet Wt. (g) |
|---|---|
| 1 | 951 |
| 2 | 651 |
| 3 | 315 |
| 4 | 1228 |
| 5 | 160 |
| *Avg.* | *661* |

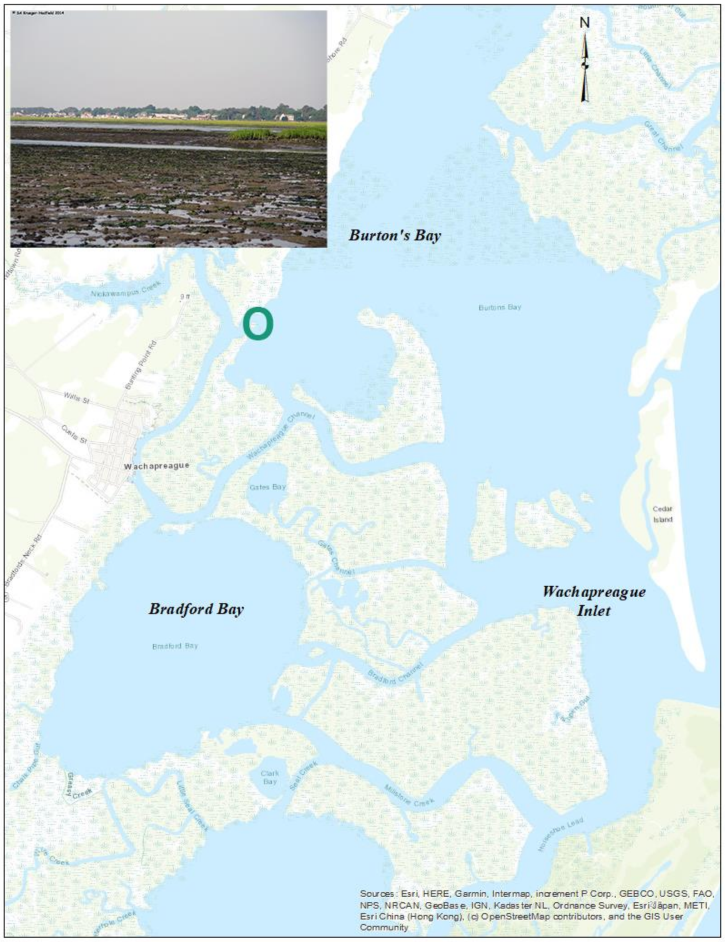

**Figure 8-1** Macroalgal mapping occurred at the Upper Haul Over (circled in green and inset image looking southwest towards Wachapreague).

**Figure 8-2** Multispectral drone used for aerial imaging near Wachapreague, VA.

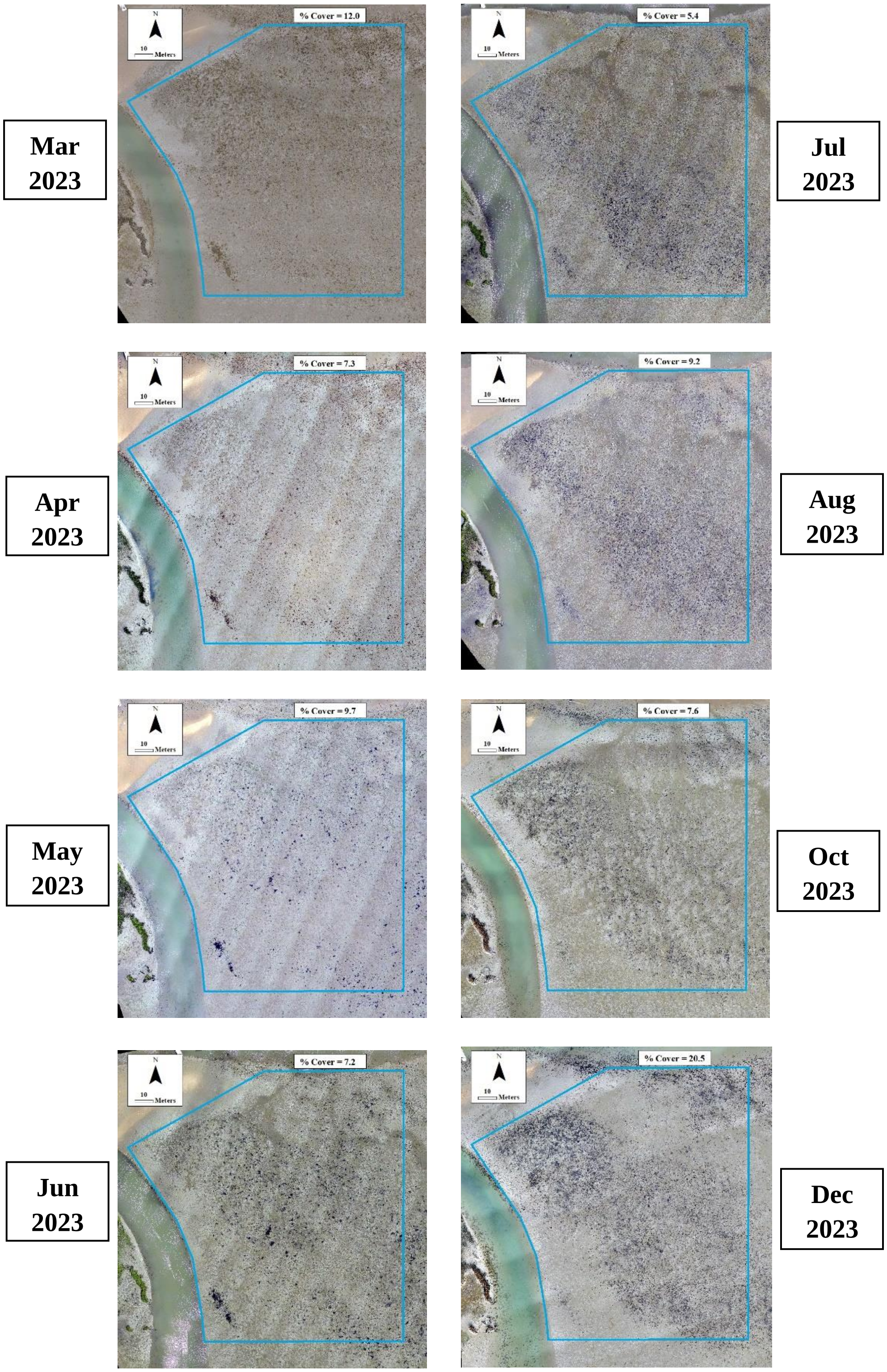

**Figure 8-3** Comparison of visible wavelength orthomosiacs from March, April, May, June, July, August, October, and December 2023 (study area outlined in blue). Dark areas on the mudflat are macroalgae and qualitative visual inspection of images suggest seasonal differences between sampling periods.

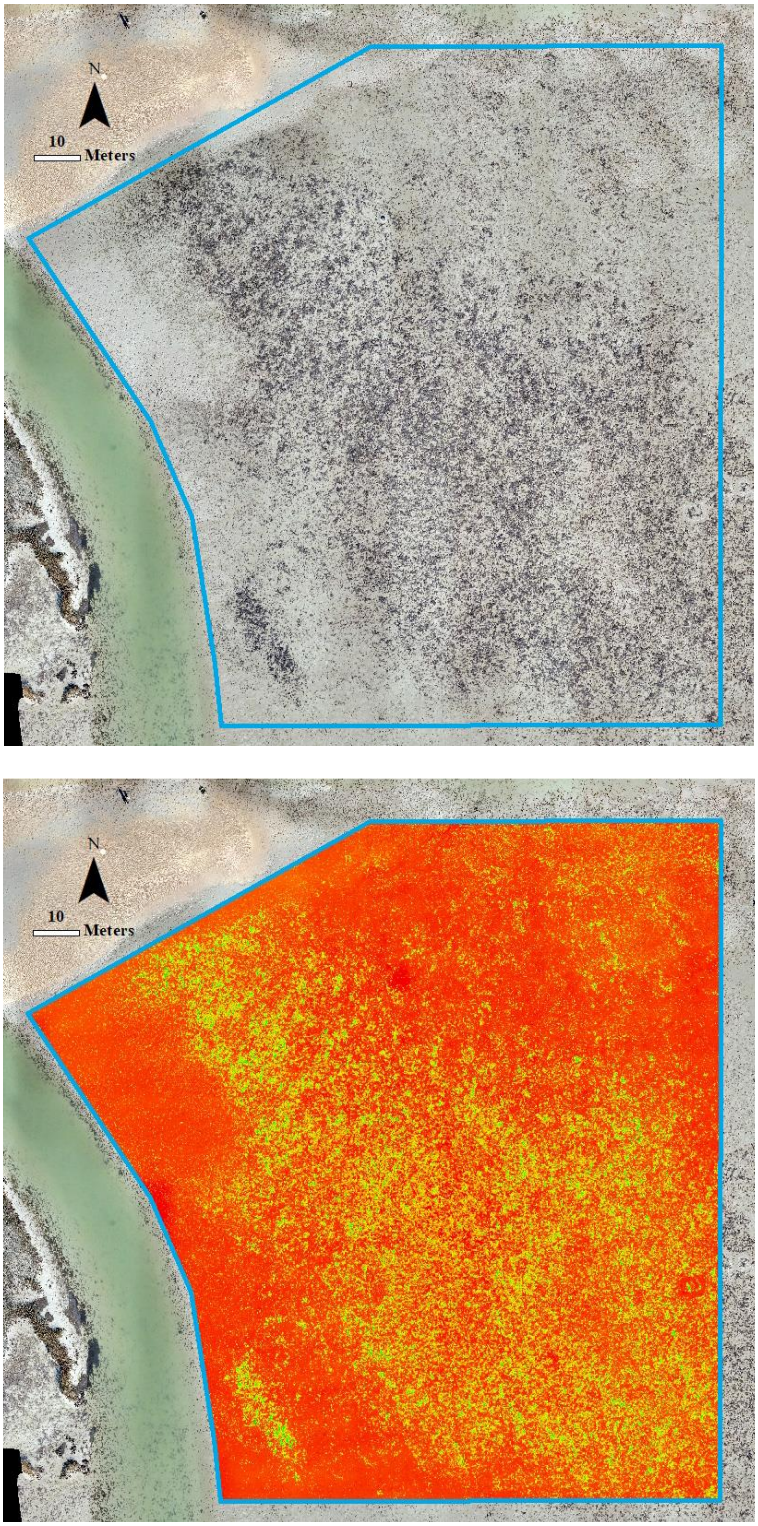

**Figure 8-4** An example of a visible wavelength orthomosaic (top) and resulting Normalized Difference Vegetative Index (NDVI; bottom) for an intertidal mudflat near Wachapreague, VA in January 2022 (study area outlined in blue). In the NDVI bottom image, green indicates macroalgae.

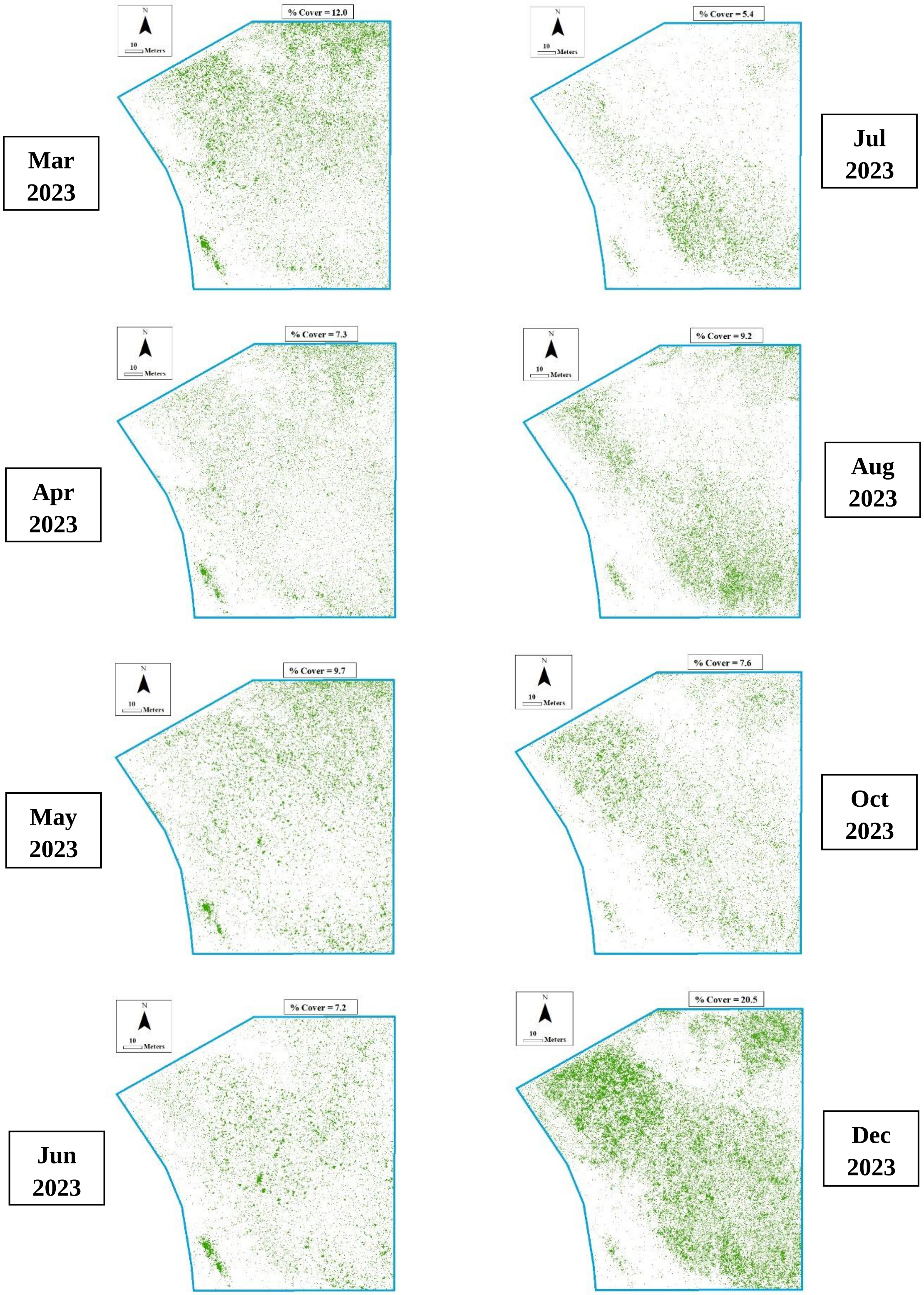

**Figure 8-5** Comparison of macroalgae coverage (green and derived from NIR imagery and their resulting Normalized Difference Vegetative Indices) from March, April, May, June, July, August, October, and December 2023 (study area outlined in blue).

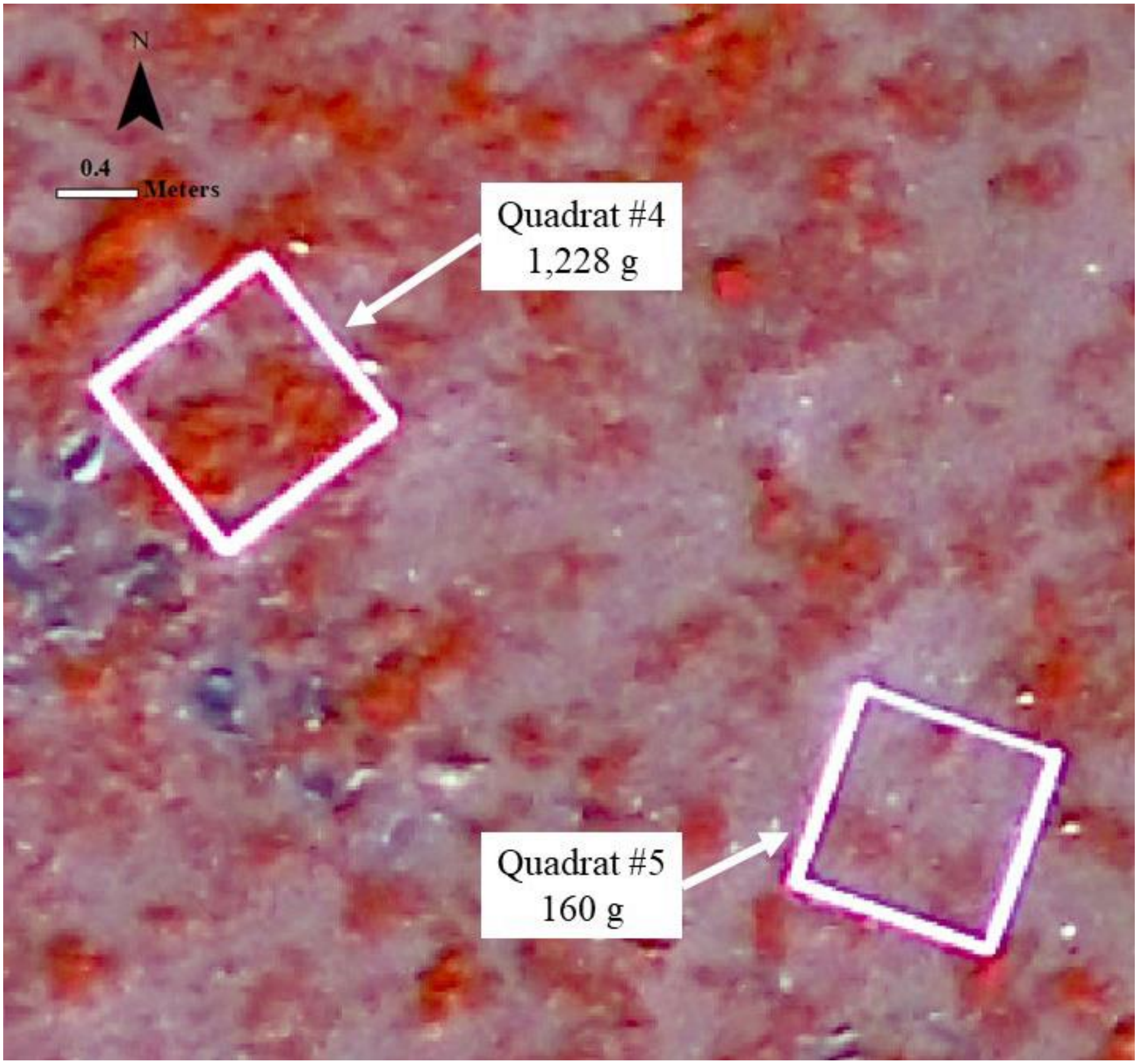

**Figure 8-6** Zoomed in area of near-infrared imagery showing 2 quadrats ($1m^2$ each) during a drone survey in November 2021 on an intertidal mudflat near Wachapreague, VA. After imaging, macroalgae in quadrats were collected and processed. Wet weight (g) of the macroalgae is noted (see Table 8-1 for details). In this image, reddish patches indicate macroalgae.

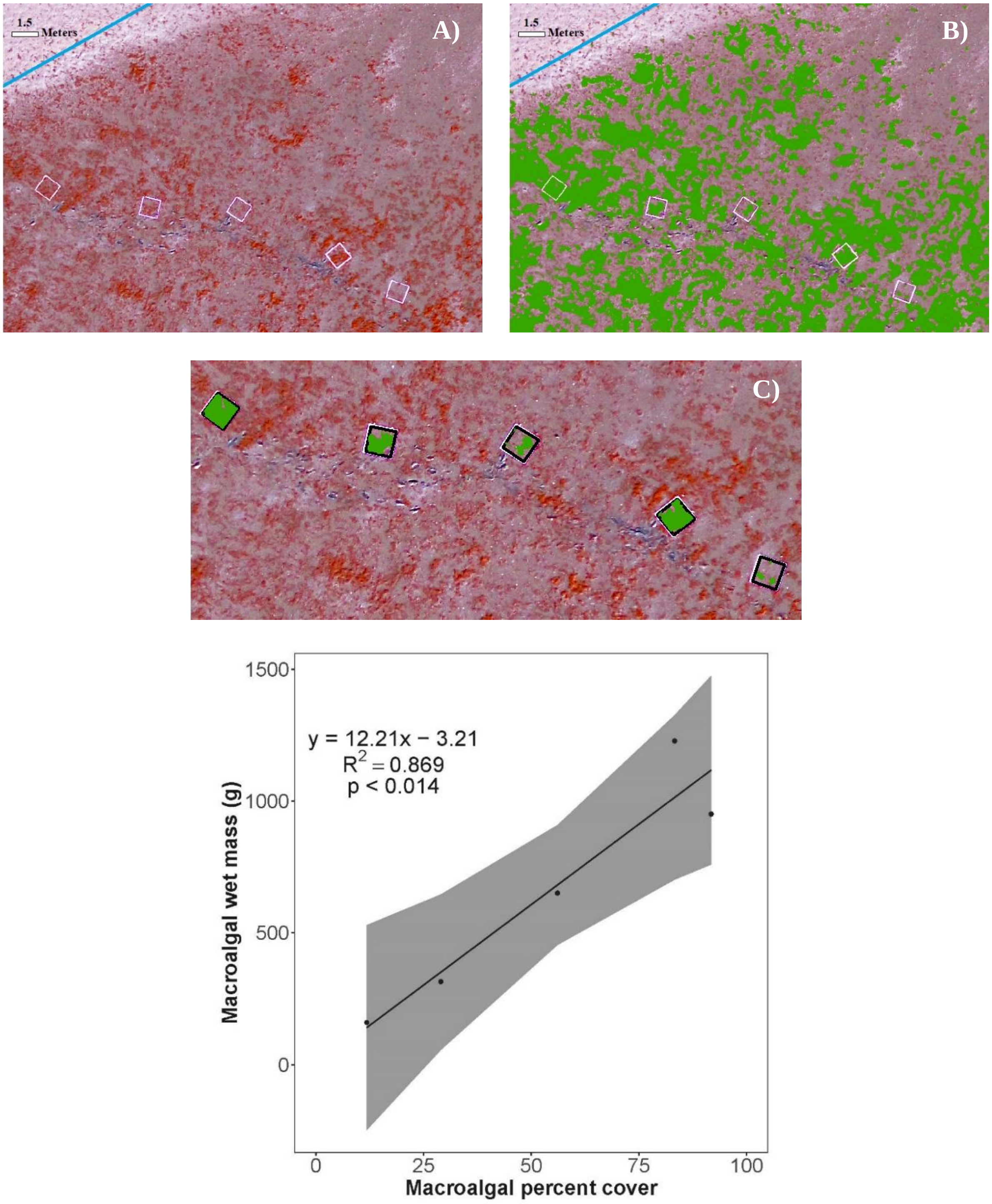

**Figure 8-7** (A) Near-infrared drone imagery from November 2021 zoomed in on 5 quadrats that were subsequently sampled for wet mass (g/m2) during the same low tide. (B) Imagery overlaid with macroalgal cover polygon (green) derived from NDVI analysis. (C) Close-up of quadrats with algal polygon clipped by quadrat. Bottom: Macroalgal cover (%), calculated via NDVI, positively and significantly correlated with field-collected wet mass (g m-2). Plot generated in R ver. 4.1.2 (R Core Team 2021) and ggplot2 (Wickham 2016).

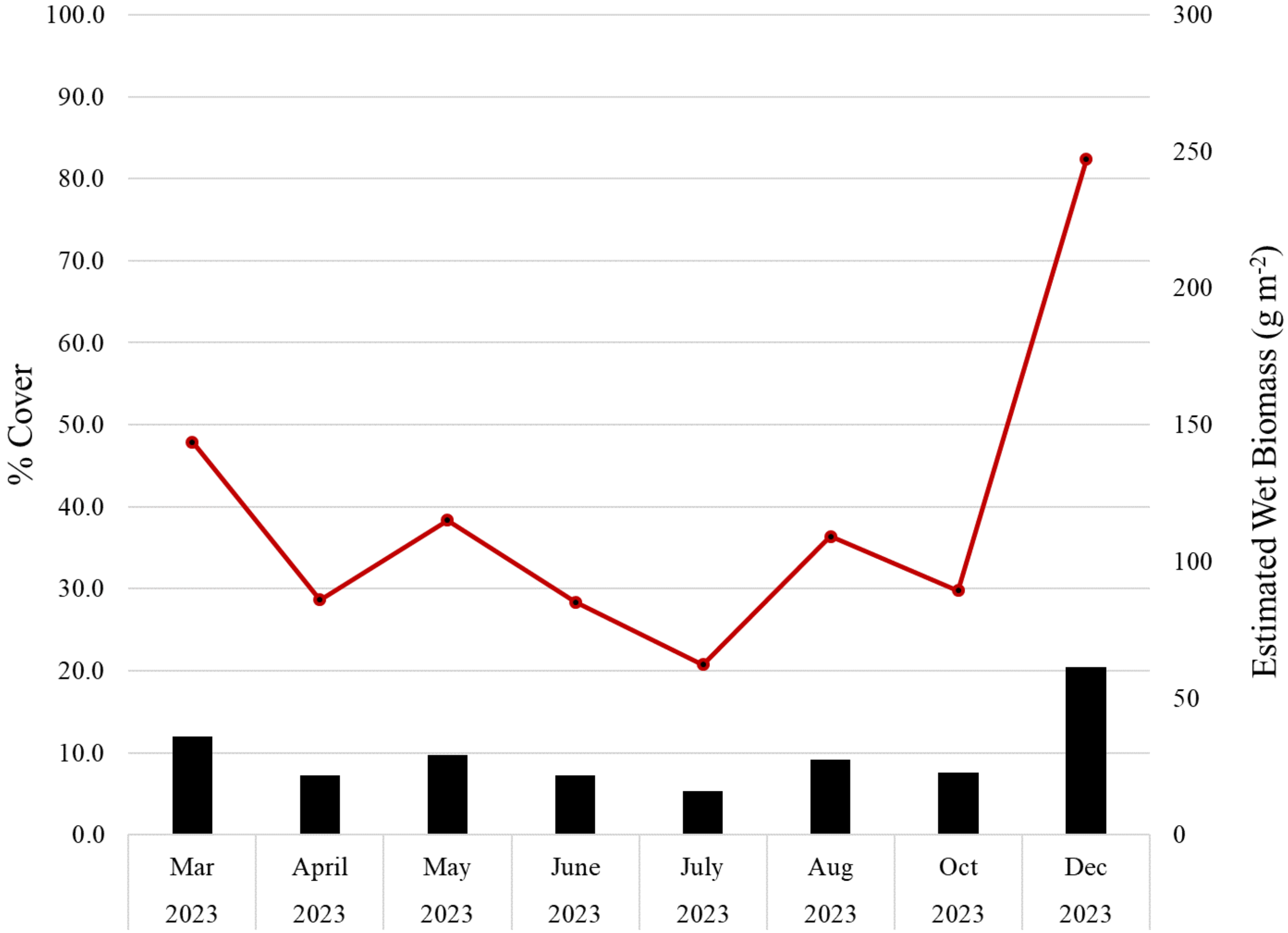

**Figure 8-8** Macroalgae % cover (black bars) and associated estimated wet biomass (g m$^{-2}$; red line) during seasonal drone surveys from March to August 2023, October, and December 2023 at an intertidal mud flat near Wachapreague, VA. Estimated wet biomass was calculated based on November 2021 field sampling (see results and Figure 8-7).

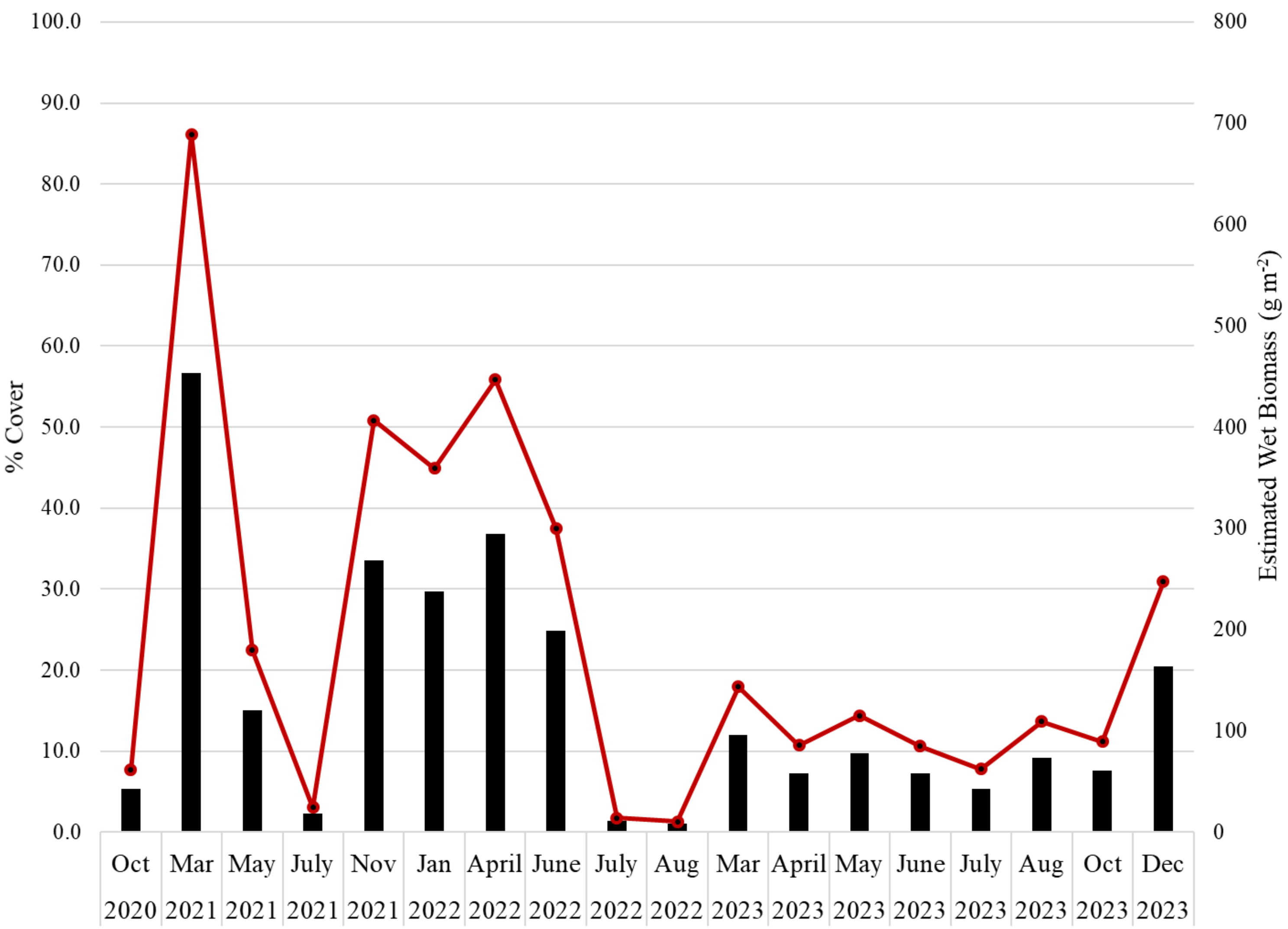

**Figure 8-9** Macroalgae % cover (black bars) and associated estimated wet biomass (g m$^{-2}$; red line) during intermittent seasonal drone surveys from October 2020 to December 2023 at an intertidal mud flat near Wachapreague, VA. Estimated wet biomass was calculated based on November 2021 field sampling (see results and Fig. 8-7).

# Chapter 9. Saltmarsh: Dieback Area Mapping

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | | Complete | | Complete | | Planned |

## Introduction

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

Starting in approximately 2011, areas of marsh dieback were observed in Nickawampus and Finney Creeks, north of the Eastern Shore Laboratory, and these areas have expanded (Gutsell 2016). Once prolific Spartina (*Sporobolus alterniflorus*) marshes have converted to mudflats with micro and macro algae production. Several researchers have made preliminary investigations without significant results, including transplants of Spartina (Luckenbach and Perry, pers. comm.), plugs of plants and organisms from die back areas into healthy marsh (Ross and Snyder, unpublished), and an investigation into environmental variables that might affect Spartina survival and growth (Gutsell 2016). No direct cause of the dieback and its persistence has been identified to date.

In conjunction with a College of William & 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 Status

Work on this parameter was not planned for 2023. We plan to continue monitoring this area in 2024. Methodology and data from 2022 can be found here: https://scholarworks.wm.edu/reports/2849/

Ross, P. G., and Snyder, R. A. (2023) Ecological Monitoring Program at VIMS ESL: Annual report 2022. VIMS Eastern Shore Laboratory Technical Report No. 11. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/pc3t-me16

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# Chapter 10. Oyster Settlement

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Completed | Completed | Planned |

## Introduction

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

Quantifying the initial settlement of recently metamorphosed oyster larvae is a useful metric for monitoring the status and future potential for the oyster population and its continued biogenic renewal of shelly, hard substrate. Settlement rates are assayed by quantifying settlement on artificial substrates. Oyster larvae drift as plankton in coastal waters for up to 21 days and can disperse over large areas depending on hydrodynamics and other 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 Chesapeake 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 and formally established 5 monitoring stations in 2018 as part of the EMP. 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. 10-1) from May 16 to November 27, 2022. Settlement arrays consist of vertical assemblies of six ceramic tiles (10.8 cm x10.8 cm) hung in the water column within 0.5 m of the seabed (Fig. 10-2). 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 (Fig. 10-2). The number of oysters were counted on the downward facing, unglazed side of tiles and standardized by tile surface area and the number of 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 five 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 using a tabular format that includes comparing the current year to various longer-term averages over many sites in Chesapeake Bay. We have used their format as a guide to organize and present EMP settlement data (e.g. see Table 10-1). The current 2014-2022 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 six years of data in Table 10-1. 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 the Eastern Shore of Virginia's seaside 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.

## 2023 Results & Discussion

As in previous years, considerable spatial variation between the five sites was observed for cumulative annual oyster settlement for the 2023, ranging from 10,363 to 309,371 oysters m$^{-2}$ (Table 10-1 and Fig. 10-3). This represented a considerable increase at all stations for 2023 (Table 10-1). The overall settlement season lasted 133 days between 20-June and 31-Oct (Table 10-2). Weekly settlement rates also were extremely high and varied spatially; these were highest at site #1 (ESL), with the other stations having lower settlement (Fig. 10-4). Generally, there was a small peak during late-June/early-July with another much larger extended peak in late-July/August and a gradual decrease into mid-September. Lower and sporadic settlement continued until late-October. Peak weekly settlement rates approached 107,000 oysters m$^{-2}$ at one of the five sites, with three sites peaking at over 15,000 oysters m$^{-2}$ and the other site peaking just below 5,000 oysters m$^{-2}$. It should be noted that we have not defined the relative preference of oyster larvae to settle on the undersides of ceramic plates versus natural substrates such as other oyster shells or live oyster reef materials. Our data are thus a uniform indicator of the potential for larval settlement and not an absolute measure of recruitment.

Based on data for oyster settlement from 2023, it is clear that many more larvae were present in the coastal lagoon and tidal creek system near Wachapreague relative to recent years. Hydrodynamics of tidal flushing and residence time of water masses may affect this, especially if a given area represents a nodal point where ebbing and flooding tides would concentrate plankton. The higher levels of planktonic chlorophyll seen in these sites may also support this idea (Chapter 4). We expect these settlement rates to translate into high recruitment rates and, ultimately, a vigorous and self-sustaining local oyster population as long as intertidal/subtidal hard substrate is available for settlement. Anecdotally, the past few years we have observed oyster clumps accumulating along Wachapreague Channel mud banks below the lower Spartina limit where oysters have been settling out on scattered shells. Should this recruitment trend continue, we may see more substantial fringing reefs develop along this waterway.

Environmental conditions, predation, and disease variables certainly have the capacity to impact the timing and intensity of both oyster spawning and subsequent settlement (e.g., Ortega and Sutherland 1992, Mann et al. 2014) and mortality (Mann et al. 2014). A persitent drought in the summer of 2022 is suspected to be a driver of the unique pattern observed this past year, and likely a cause of the decreased microalgae growth in biofilms as well (Chapter 7). As we accumulate several years of data, we will be better able to compare yearly water quality data from Chapter 3 to EMP data (such as oyster settlement in this chapter) to explore these relationships. Temperature is certainly a key factor in stimulating seasonal spawning. The date of critical temperature for spawning and its potential to change with warming surface waters is a variable we hope to define. Although directly measuring oyster predation is not part of EMP, numbers of mud crabs and oyster drills on reefs (Chapter 13) and information on oyster disease dynamics will be useful to discern factors affecting the oyster population.

As more years of standardized data are collected for oyster settlement, we anticipate being better able to categorize the range of spat recruitment intensity both temporally and spatially. Given the historical collapse of seaside oyster populations and the potential for coastal change, establishing a long-term record of oyster spat recruitment will provide important sentinel for hard substrate habitats and their associated communities (see Chapter 13).

### Comparison to Previous Years

Overall oyster settlement was well above average, although site-specific settlement was varied, with two sites having greater than +1,000% cumulate settlement relative to the 2014-2022 average (Table 10-1). The ESL site (#1) and Inlet site (#5) were consistently the sites with the highest cumulative settlement in 2014, 2016, 2018, 2019 and 2020 (Table 10-1; note there is no data for the Inlet site for 2014). This pattern held for the ESL site (#1) but not for the Inlet site (#5) during 2021-2023. It is important to note that the immediate vicinity of site #5 has dramatically changed since 2020 and the inside north end of Parramore Island has seen substantial sand movement and accumulation. We had to move this site from the backside of Parramore Island, across the channel to the marsh area immediately west of the island to accommodate these changes.

For all sites combined, the seasonal period of oyster settlement (maximum number of days) was longer for 2023 compared to 2021-2022, but similar to the 2014-2020 average (Table 10-2). This longer period was mainly influenced by a relatively late sessation of settlement at several sites in 2023 (Table 10-2).

Mean intra-annual timing and weekly settlement rates for all five sites combined in 2023 exhibited a unique pattern relative to previous years with settlement generally occurring at very high levels throughout the the entire summer (Fig. 10-5). 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). In 2023, the relative intensity of these peaks is high over an extended period which is a deviation from what has typically been observed in seaside coastal lagoons. Interestingly, the peaks of mean settlement rates seemed to be slowly shifting later in the summer from 2020-2022, and data from 2023 may support this, however the intensity and temporal breadth made it difficult to compare this year to previous patterns (Fig. 10-5). Extremely high settlement rates, combined with a relatively long settlement time period, made this year one of the highest potential settlement years we have documented. Whether this is a trend or simply interannual variation caused by annual acute meteorological/water quality parameters (e.g. rainfall/salinity and/or water temperature) remains to be seen.

## 2023 Acknowledgements

We would like to thank Emory Harned, Oscar Melendez Vera, Hunter Rippon and Carter Nottingham for field and/or lab assistance.

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**Table 10-1**. Summary of annual cumulative oyster settlement (# m$^{-2}$) at each of 5 sites near Wachapreague, VA from 2014-2023. Sampling prior to 2018 was not part of the Ecological Monitoring Program but the same protocols were used at the same sites. General intensity color scale for individual years only is shown below table.

| **Site #** | **2014** | **2016** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **Average Previous Years (2014-2022)** | **2023 vs. Avg. (%)** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-ESL | 46,462 | 5,558 | 24,795 | 23,392 | 41,974 | 73,713 | 70,161 | 309,371 | 40,865 | 657.1 |
| 2-Burton's Bay | 23,977 | 424 | 7,801 | 5,044 | 16,944 | 8,743 | 7,354 | 65,716 | 10,041 | 554.5 |
| 3-Finney Creek | 1,579 | 509 | 1,029 | 833 | 4,108 | 10,833 | 6,307 | 45,702 | 3,600 | 1169.6 |
| 4-Bradford Bay | 775 | 734 | 5,994 | 2,442 | 8,480 | 7,471 | 18,646 | 116,865 | 6,363 | 1736.6 |
| 5-Wach. Inlet | -- | 5,117 | 19,933 | 62,471 | 98,523 | 9,547 | 4,269 | 10,363 | 33,310 | -68.9 |
| *Average for All Sites Combined* | *18,198* | *2,468* | *11,910* | *18,836* | *34,006* | *22,061* | *21,347* | *109,603* | *18,836* | *481.9* |

Light settlement (<1,000 spat/m$^2$)

Moderate settlement (1,000-10,000 spat/m2)

Average settlement (10,000-20,000 spat/m2)

Heavy settlement (20,000-30,000 spat/m2)

Extremely heavy settlement (>30,000 spat/m2)

**Table 10-2**. Summary of oyster settlement timing (date) and maximum duration (# days) at each of 5 sites near Wachapreague, VA from 2014-2023. Sampling prior to 2018 was not part of the Ecological Monitoring Program but the same protocols were used at the same sites.

| **Site #** | **Date Metric** | **2014** | **2016** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **Average Previous Years (2014-2022)** | **2023 vs. Avg. (%)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1<br>ESL | # days | 96 | 125 | 132 | 154 | 161 | 126 | 120 | 119 | 131 | -8.9 |
| | Begin date | 26-Jun | 21-Jun | 12-Jun | 20-May | 27-May | 8-Jun | 14-Jun | 20-Jun | | |
| | End date | 30-Sep | 24-Oct | 22-Oct | 21-Oct | 4-Nov | 12-Oct | 12-Oct | 17-Oct | | |
| 2<br>Burton's Bay | # days | 91 | 111 | 111 | 126 | 112 | 113 | 120 | 133 | 112 | 18.8 |
| | Begin date | 20-Jun | 5-Jul | 3-Jul | 3-Jun | 29-Jun | 8-Jun | 14-Jun | 20-Jun | | |
| | End date | 19-Sep | 24-Oct | 22-Oct | 7-Oct | 19-Oct | 29-Sep | 12-Oct | 31-Oct | | |
| 3<br>Finney Creek | # days | 118 | 125 | 132 | 126 | 71 | 112 | 114 | 97 | 114 | -14.9 |
| | Begin date | 26-Jun | 21-Jun | 12-Jun | 3-Jun | 29-Jun | 22-Jun | 14-Jun | 29-Jun | | |
| | End date | 22-Oct | 24-Oct | 22-Oct | 7-Oct | 8-Sep | 12-Oct | 6-Oct | 4-Oct | | |
| 4<br>Bradford Bay | # days | 62 | 111 | 106 | 126 | 71 | 98 | 114 | 133 | 98 | 35.3 |
| | Begin date | 26-Jun | 5-Jul | 26-Jun | 20-May | 29-Jun | 6-Jul | 14-Jun | 20-Jun | | |
| | End date | 27-Aug | 24-Oct | 10-Oct | 23-Sep | 8-Sep | 12-Oct | 6-Oct | 31-Oct | | |
| 5<br>Wach. Inlet | # days | -- | 125 | 111 | 126 | 119 | 114 | 106 | 124 | 117 | 6.1 |
| | Begin date | -- | 21-Jun | 3-Jul | 3-Jun | 22-Jun | 6-Jul | 28-Jun | 29-Jun | | |
| | End date | -- | 24-Oct | 22-Oct | 7-Oct | 19-Oct | 28-Oct | 12-Oct | 31-Oct | | |
| *All Sites Combined* | *Max # days* | *118* | *125* | *132* | *154* | *161* | *126* | *120* | *133* | *134* | *-0.5* |
| | *Begin date* | *20-Jun* | *21-Jun* | *12-Jun* | *20-May* | *27-May* | *8-Jun* | *14-Jun* | *20-Jun* | | |
| | *End date* | *22-Oct* | *24-Oct* | *22-Oct* | *21-Oct* | *4-Nov* | *28-Oct* | *12-Oct* | *31-Oct* | | |

**Figure 10-1** Locations of 5 oyster settlement monitoring sites near Wachapreague, VA for 2018-2023 (red polygons denote the ESL-EMP study areas).

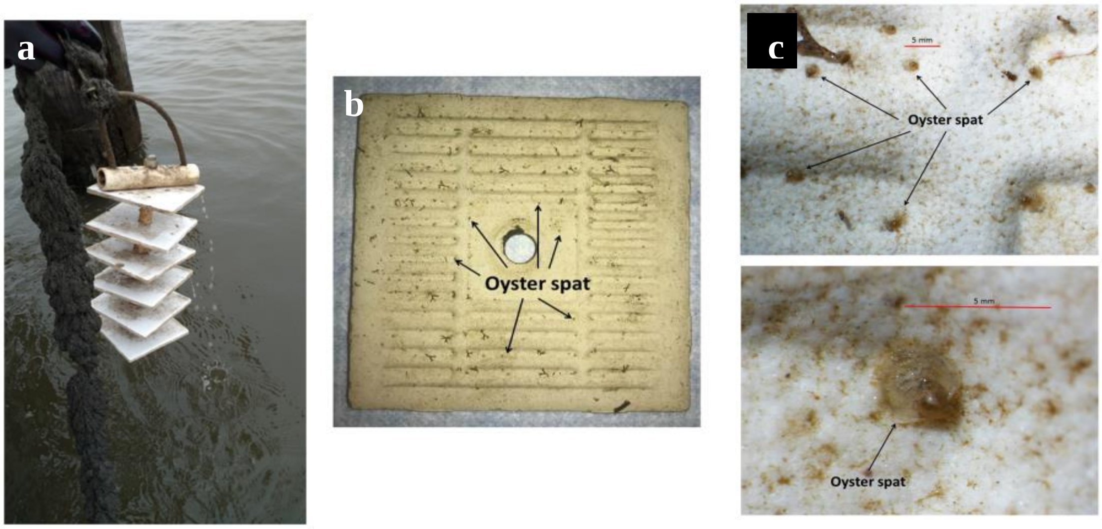
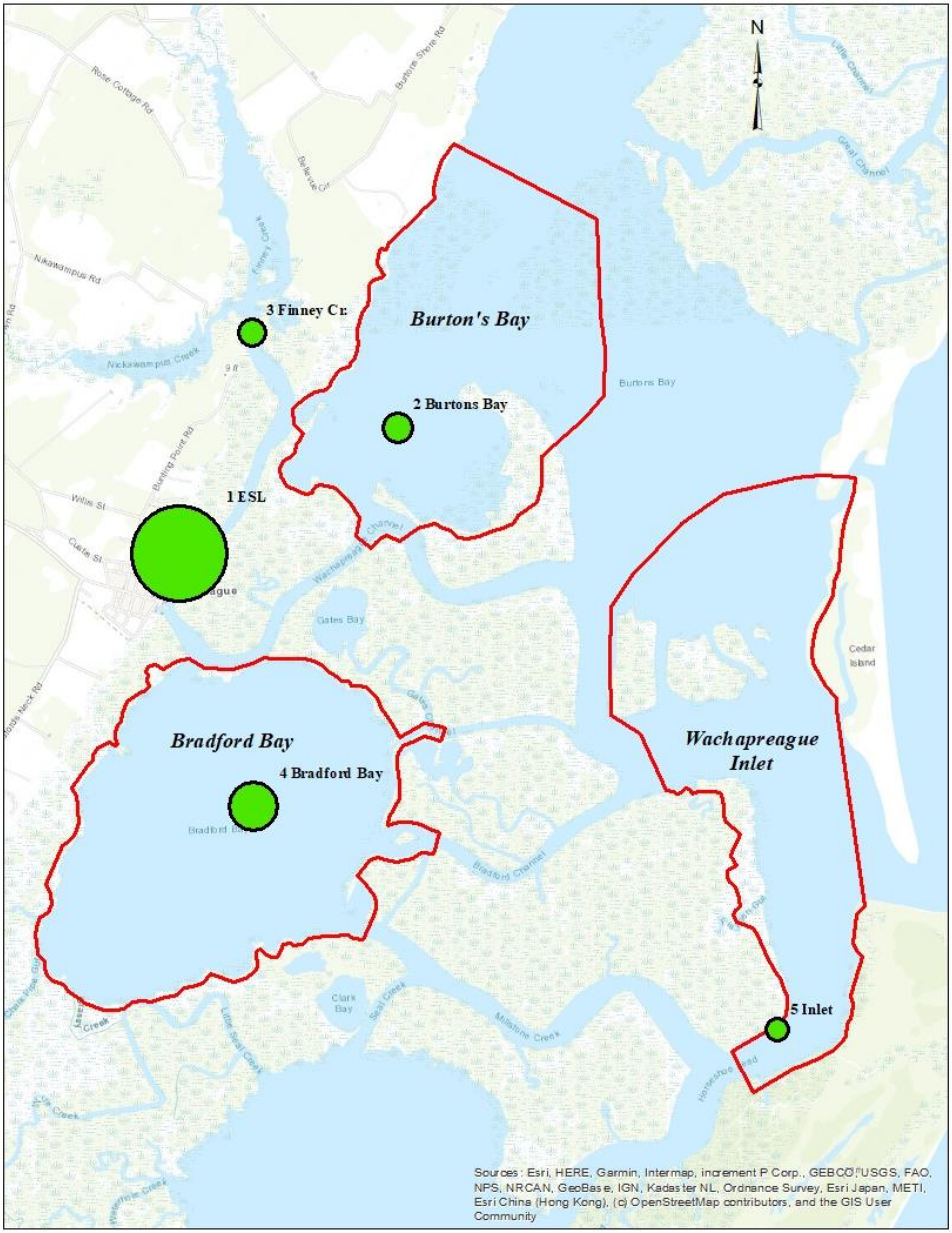


**Figure 10-2** Settlement monitoring: a) array being retrieved in field b) tile with oyster spat and c) images of oyster spat on unglazed side of settlement tiles under 2 magnifications.



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

**Figure 10-3** Spatial pattern of 2023 cumulative oyster settlement (# oysters m$^{-2}$) at 5 monitoring sites near Wachapreague, VA. Size of symbols are the proportion of the total settlement to visualize the scale of differences between sites (red polygons denote the ESL-EMP study areas).

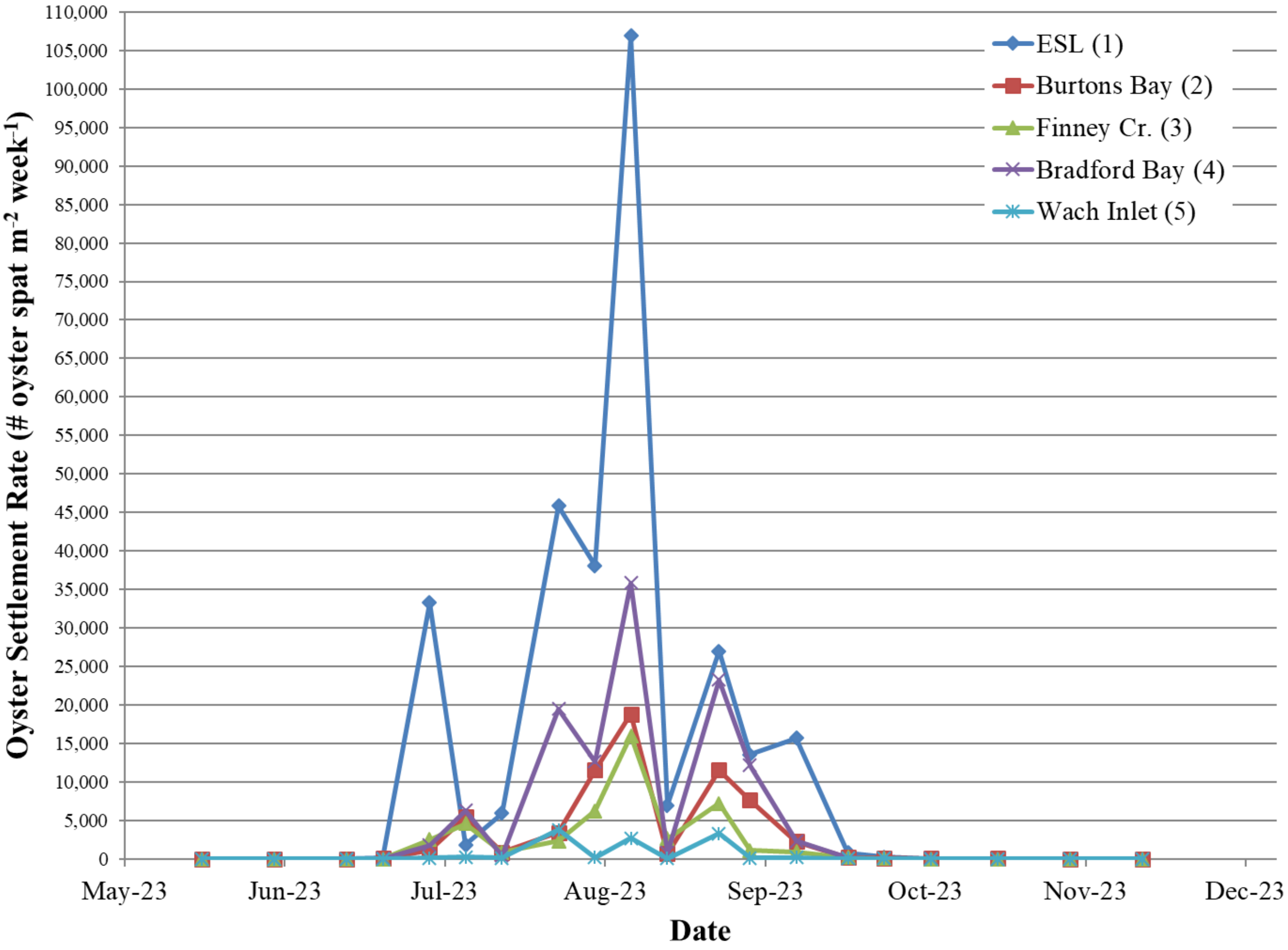


**Figure 10-4** Weekly oyster settlement rate (# spat $m^{-2}$ $week^{-1}$) at 5 monitoring stations near Wachapreague, VA during 2023.

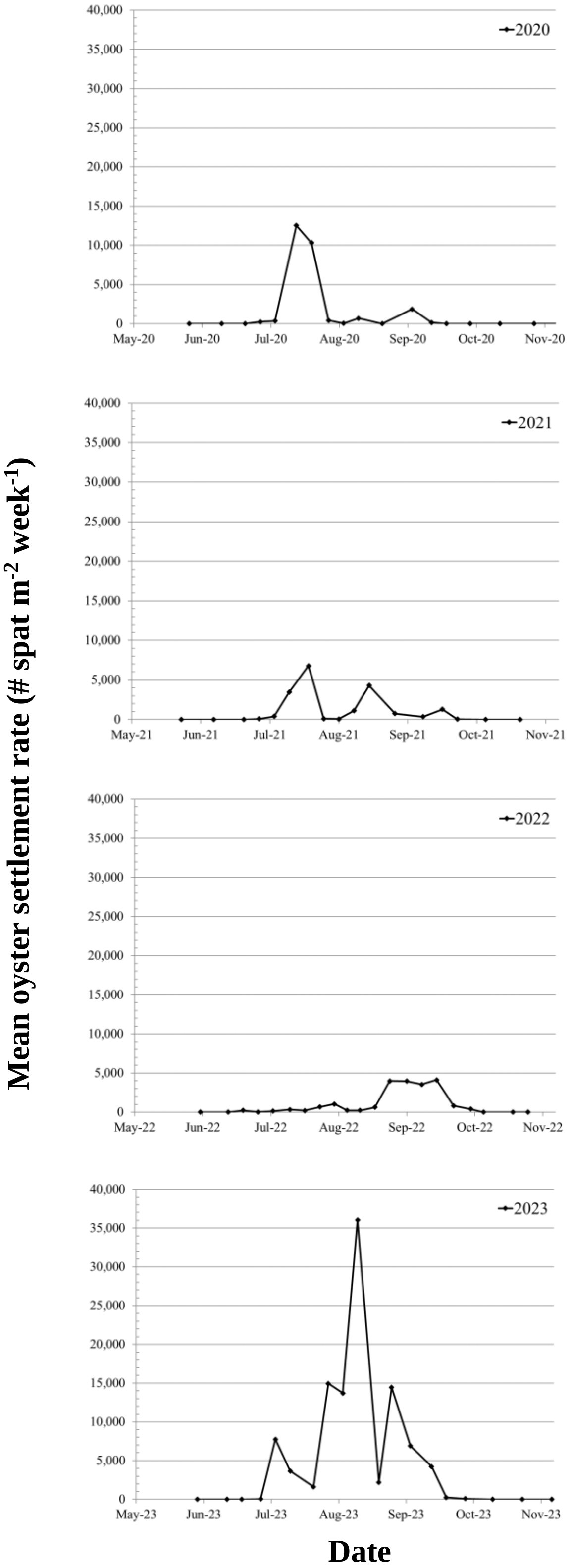


**Figure 10-5** Pooled mean oyster settlement rate (# spat m$^{-2}$ week$^{-1}$) for 5 monitoring stations near Wachapreague, VA by date during 2020-2023.

# Chapter 11. Oyster Population Demographics

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### 7-year sampling plan:

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Completed | Completed | 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 and 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 10) 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. Because of the unique nature of Seaside ESVA reefs, these metrics are not directly comparable to assessment criteria for Chesapaeake Bay reefs.

## Study Area & Methods

We selected two intertidal patch reefs within each of the three EMP geographical areas to monitor (6 reefs total; Fig. 11-1). These were reefs that appear to be representative of other sites throughout the area. At each reef, two haphazard quadrat samples (25 cm x 25 cm; 0.0625 $m^2$) were collected to 15 cm deep. One of these was located within the upper ½ of reef (crest) and one in the lower ½ of reef (flank). Reefs were sampled during June 1-2, 2023.

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 13. Oysters were counted and measured (longest hinge-lip to nearest mm). Tissue from oysters $\geq$ 35 mm were removed and pooled into a single sample for each quadrat. This size oyster is generally considered an oyster that is not a recently settled recruit and we can efficiently remove all tissue. Tissue was dried to a constant temperature at 80-100° 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.

## 2023 Results & Discussion

The overall oyster density on sampled reefs ranged from 144 to 2,760 individuals $m^{-2}$ (Table 11-1). Individual reef densities were quite variable and there were often substantial differences between crest and flank samples within reefs. Although density of individuals is useful information, the density in terms of dry tissue biomass (g $m^{-2}$) is often more descriptive of the oyster population since it effectively accounts for abundance and size in one metric. The biomass density of the oyster population $\geq$ 35 mm on sampled reefs ranged from 16 to 453 g $m^{-2}$ (Table 11-1) and similar differences, as noted above, were seen within reefs.

The size frequency distribution for an oyster population can often be used to generally describe its age structure. Overall, distribution of oysters sampled on all reefs ranged from new recruits (<35 mm) up to mature adults ($\geq$75 mm) including several year classes in between. Although quite variable between patch reefs, generally there were multiple age classes present in most samples. Size frequency distribution pooled for the entire EMP study area is summarized in Figure 11-2 for 2023. Data for specific geographic areas or individual reefs are available upon request.

In addition to size frequency distributions, to further characterize oyster size on patch reefs, we report quantities of oysters in three traditional size categories: *"Spat" (<35 mm), "Small" (35-75 mm)* and *"Market" (>75 mm)*. These categories are modified from categories that have historically been used by the oyster industry and ongoing Chesapeake Bay monitoring efforts (see Southworth and Mann 2018). Generally, individual reefs showed a similar pattern: Spat>Small>Market for 2023 (Table 11-2).

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 six years of data suggest that inter-annual variation is to be expected and that there is a generally stable oyster population.

There were some slight geographic differences noted. Unlike previous years, generally similar oyster densities were observed in all three study areas (Table 11-1). Drivers of both recruitment success and reef development are likely related to food quality and availability, predation, and disease. Relationships between the oyster population, oyster settlement and the organismal community (potential predators/competition) is complex and also contributes to oyster demographics. We plan to explore these relationships once multiple years of data have been collected. However, status and trends for oysters within individual reefs to define regional patterns will be a main primary focus of this aspect of the EMP.

## Comparison to Previous Years

Of the individual six reefs sampled, about half were above and half below the average of the previous 5 years (2018-2022; Table 11-1). When pooled by geographic regions, some decreases in oyster density (# $m^{-2}$) and biomass (g $m^{-2}$) were noted for 2023 compared to 2022, although still high relative to 2018-2021 (Fig. 11-4).

A cursory analysis of these trends suggests an overall positive linear relationship (i.e. increasing oyster population) from 2018-2023 (Fig. 11-4), both in terms of density (#$m^{-2}$) and biomass (g dry tissue $m^{-2}$). This increase is the steepest for the Inlet geographic area and the relationship is strongest for the Bradford Bay geographic area (Fig. 11-5).

Inter-annual changes were variable by reef for oyster size. Pooled size distributions for the entire monitoring program show some minor age structure variations, especially in the larger (>90 mm) sizes (Fig. 11-6). These are to be expected in a wild oyster population, but it is interesting that these older age classes seem to be increasing over time. Reefs were pooled together by study area and exhibit a generally consistent proportion of various size classes of oysters (Fig. 11-7).

## 2023 Acknowledgements

We would like to thank Emory Harned, Oscar Melendez Vera, and Hunter Rippon for field and/or lab processing assistance.

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Kellogg, L. M., J. Cornwell, J. Owens, M. Luckenbach, P. Ross, and T. Leggett. 2014. *Scaling ecosystem services to reef development: effects of oyster density on nitrogen removal and reef community structure.* Virginia Institute of Marine Science, College of William and Mary. http://doi.org/10.21220/V5G013

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Southworth, M. and R. Mann. 2019. *The status of Virginia's public oyster resource, 2018. Molluscan Ecology Program*, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp.

**Table 11-1**. 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 2018-2023.

**A) # $m^{-2}$**

| Study Area | Reef ID | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Previous Average (2018-2022) |
|---|---|---|---|---|---|---|---|---|
| Bradford Bay | Q1 | 704 | 1,112 | 1,344 | 432 | 1,432 | 1,776 | 1,005 |
| | Q2 | 2,016 | 2,096 | 2,096 | 2,672 | 2,376 | 2,416 | 2,251 |
| Burton's Bay | Q4 | 2,048 | 1,272 | 1,488 | 2,200 | 1,608 | 2,432 | 1,723 |
| | Q5 | 624 | 1,432 | 504 | 1,408 | 1,488 | 144 | 1,091 |
| Wach. Inlet | Q7 | 848 | 1,232 | 2,200 | 4,992 | 4,896 | 2,760 | 2,834 |
| | Q9 | 2,592 | 1,888 | 3,096 | 2,456 | 2,616 | 1,432 | 2,530 |
| *Average of All Regions Combined* | | *1,472* | *1,505* | *1,788* | *2,360* | *2,403* | *1,827* | *1,906* |

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

| Study Area | Reef ID | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Previous Average (2018-2022) |
|---|---|---|---|---|---|---|---|---|
| Bradford Bay | Q1 | 97 | 171 | 286 | 94 | 370 | 338 | 226 |
| | Q2 | 260 | 222 | 229 | 442 | 362 | 433 | 324 |
| Burton's Bay | Q4 | 146 | 165 | 168 | 300 | 334 | 453 | 261 |
| | Q5 | 113 | 131 | 28 | 148 | 74 | 16 | 85 |
| Wach. Inlet | Q7 | 168 | 232 | 266 | 429 | 846 | 442 | 397 |
| | Q9 | 357 | 305 | 598 | 322 | 516 | 222 | 387 |
| *Average of All Regions Combined* | | *190* | *204* | *263* | *289* | *417* | *317* | *280* |

**Table 11-2**. 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 2018-2023.

**A) # $m^{-2}$**

| Study Area | Size Class | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Previous Average (2018-2022) |
|---|---|---|---|---|---|---|---|---|
| Bradford Bay | Spat (<35 mm) | 724 | 968 | 888 | 856 | 912 | 964 | 870 |
| | Small (35-75 mm) | 448 | 496 | 692 | 524 | 716 | 800 | 575 |
| | Market (>75 mm) | 184 | 120 | 140 | 168 | 276 | 332 | 178 |
| | *All* | *1,356* | *1,584* | *1,720* | *1,548* | *1,904* | *2,096* | *1,622* |
| Burton's Bay | Spat (<35 mm) | 832 | 788 | 588 | 1,056 | 984 | 672 | 850 |
| | Small (35-75 mm) | 444 | 500 | 380 | 612 | 388 | 444 | 465 |
| | Market (>75 mm) | 52 | 60 | 28 | 132 | 168 | 172 | 88 |
| | *All* | *1,328* | *1,348* | *996* | *1,800* | *1,540* | *1,288* | *1,402* |
| Wach. Inlet | Spat (<35 mm) | 860 | 868 | 1,312 | 2,548 | 2,196 | 1,268 | 1,557 |
| | Small (35-75 mm) | 664 | 592 | 1,132 | 980 | 1,032 | 624 | 880 |
| | Market (>75 mm) | 196 | 96 | 204 | 196 | 516 | 204 | 242 |
| | *All* | *1,720* | *1,556* | *2,648* | *3,724* | *3,744* | *2,096* | *2,678* |

**B) %**

| Study Area | Size Class | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Previous Average (2018-2022) |
|---|---|---|---|---|---|---|---|---|
| Bradford Bay | Spat (<35 mm) | 53 | 61 | 52 | 55 | 48 | 46 | 54 |
| | Small (35-75 mm) | 33 | 31 | 40 | 34 | 38 | 38 | 35 |
| | Market (>75 mm) | 14 | 8 | 8 | 11 | 14 | 16 | 11 |
| Burton's Bay | Spat (<35 mm) | 63 | 58 | 59 | 59 | 64 | 52 | 61 |
| | Small (35-75 mm) | 33 | 37 | 38 | 34 | 25 | 34 | 34 |
| | Market (>75 mm) | 4 | 4 | 3 | 7 | 11 | 13 | 6 |
| Wach. Inlet | Spat (<35 mm) | 50 | 56 | 50 | 68 | 59 | 60 | 56 |
| | Small (35-75 mm) | 39 | 38 | 43 | 26 | 28 | 30 | 35 |
| | Market (>75 mm) | 11 | 6 | 8 | 5 | 14 | 10 | 9 |

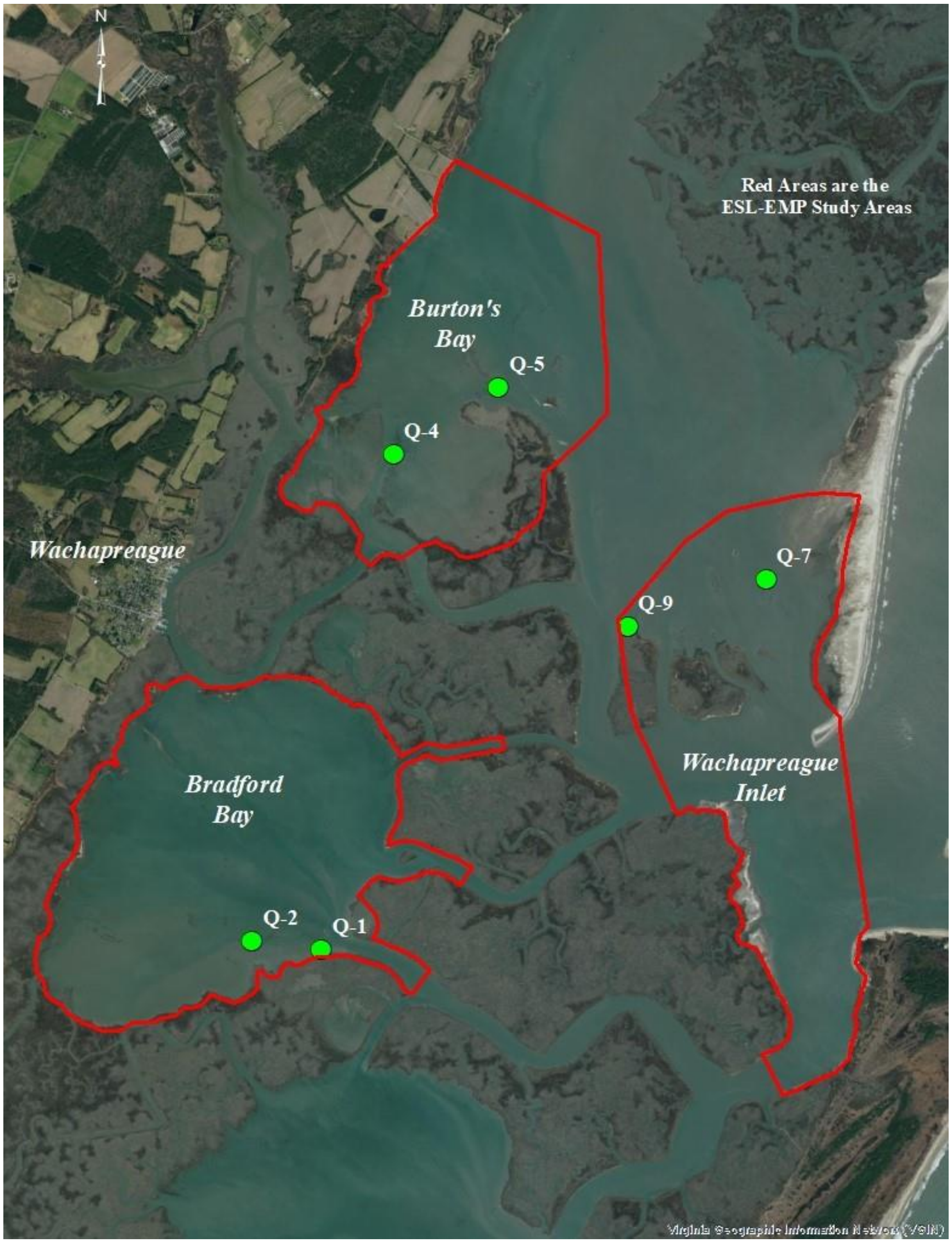


**Figure 11-1** Locations of 6 intertidal oyster reef monitoring sites near Wachapreague, VA for 2018-2023 (red polygons denote the ESL-EMP study areas).

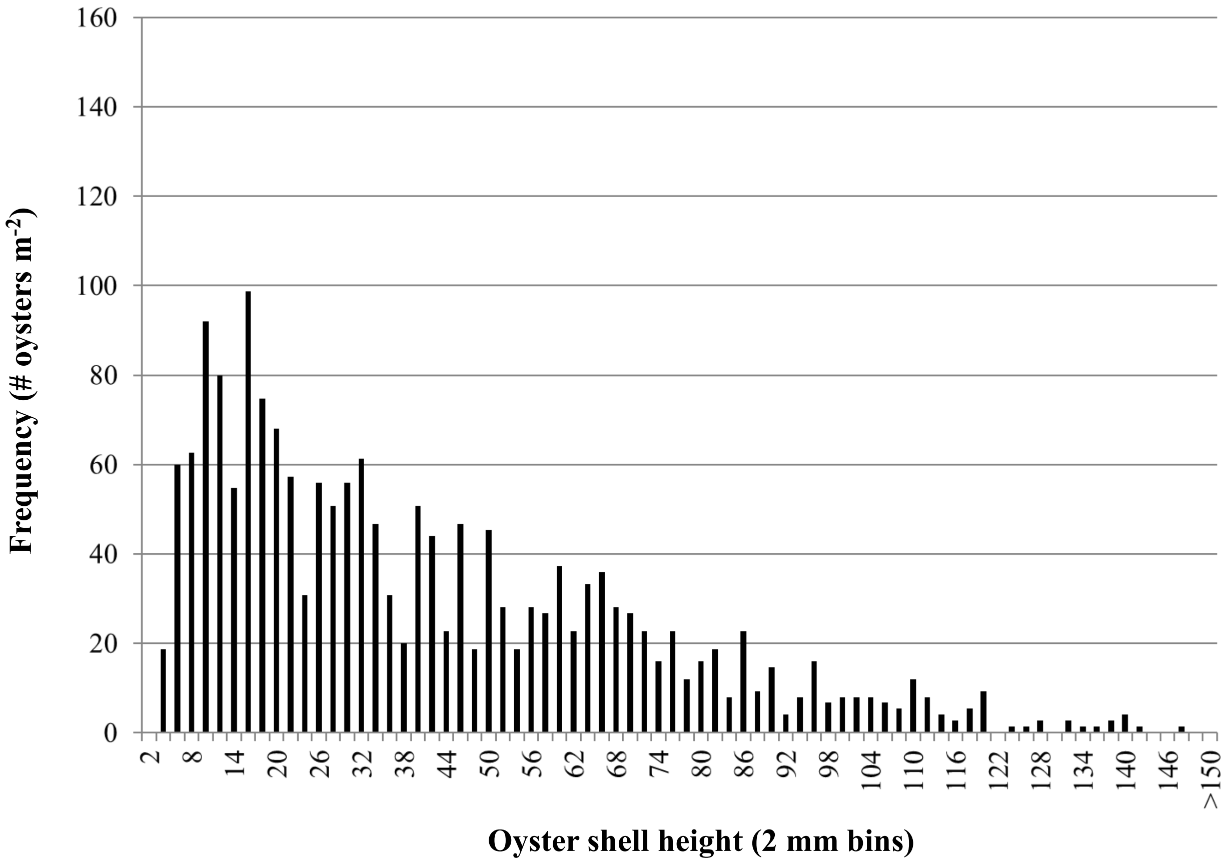
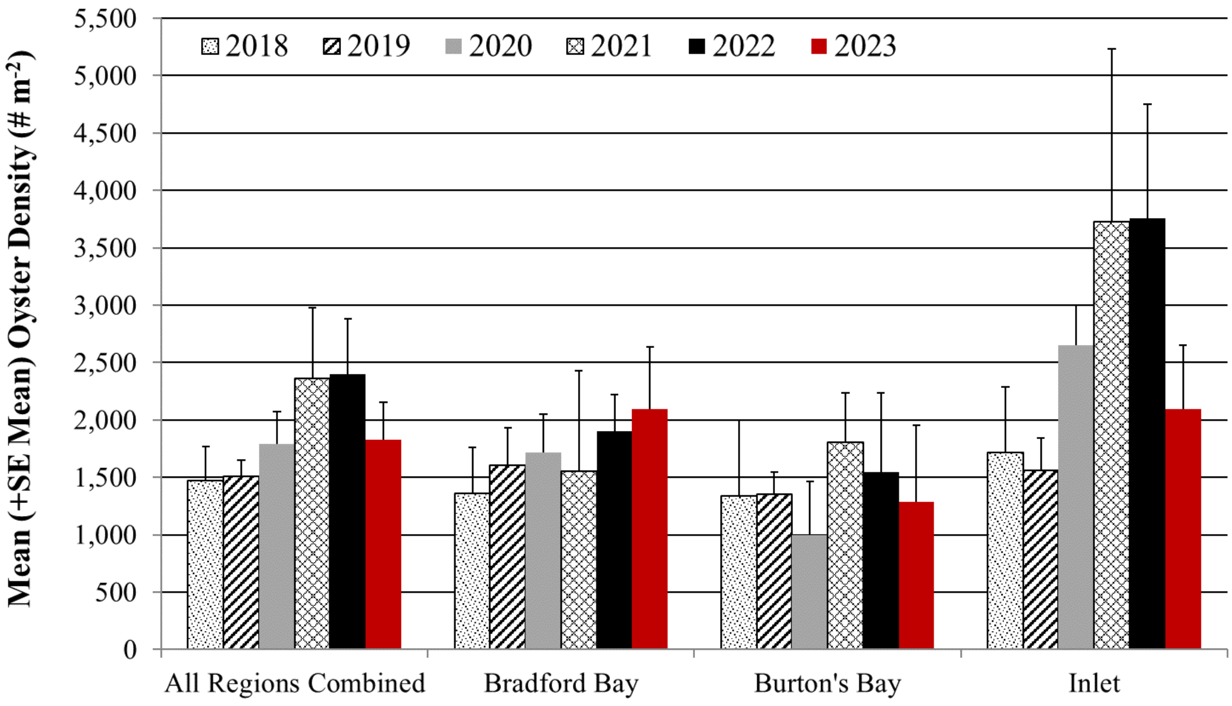


**Figure 11-2** Pooled size frequency distribution (# oysters $m^{-2}$ in 2 mm bins) of oysters found on intertidal patch reefs near Wachapreague, VA in 2023 (quad n=12).



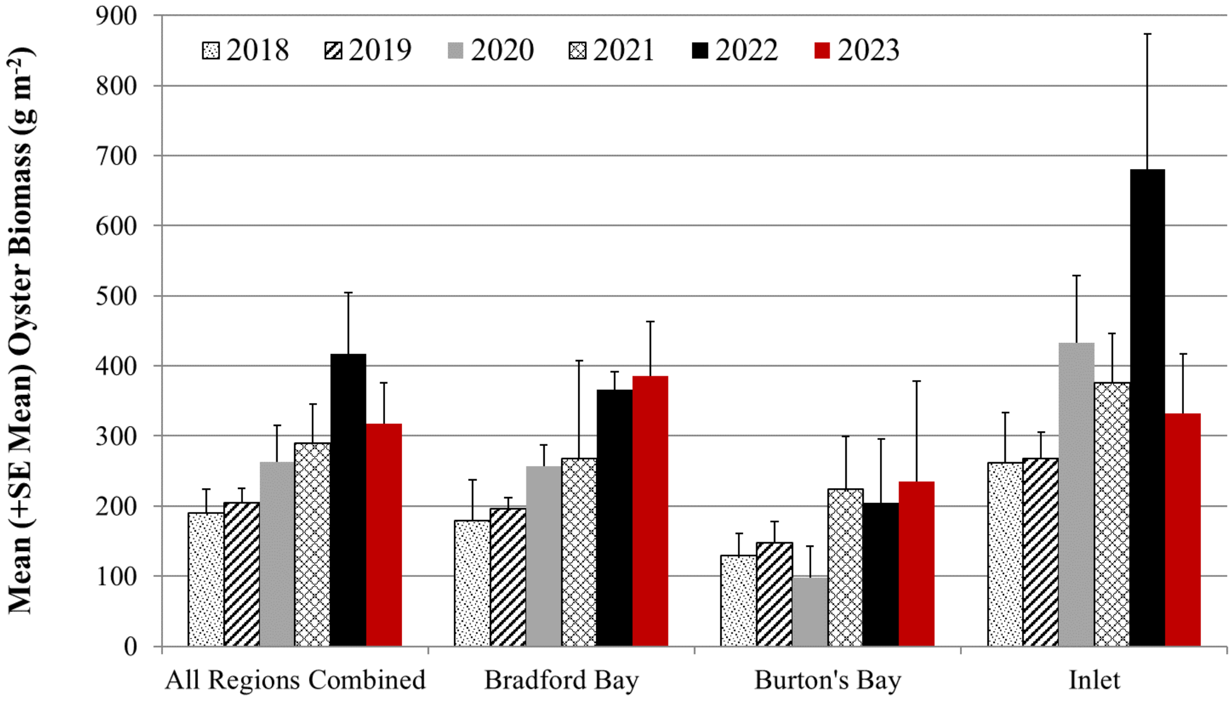


**Figure 11-3** Mean (+ SE) oyster density (# $m^{-2}$) and oyster biomass (ash-free dry wt.; g $m^{-2}$) at intertidal patch reefs in three geographic areas near Wachapreague, VA during 2018-2023.

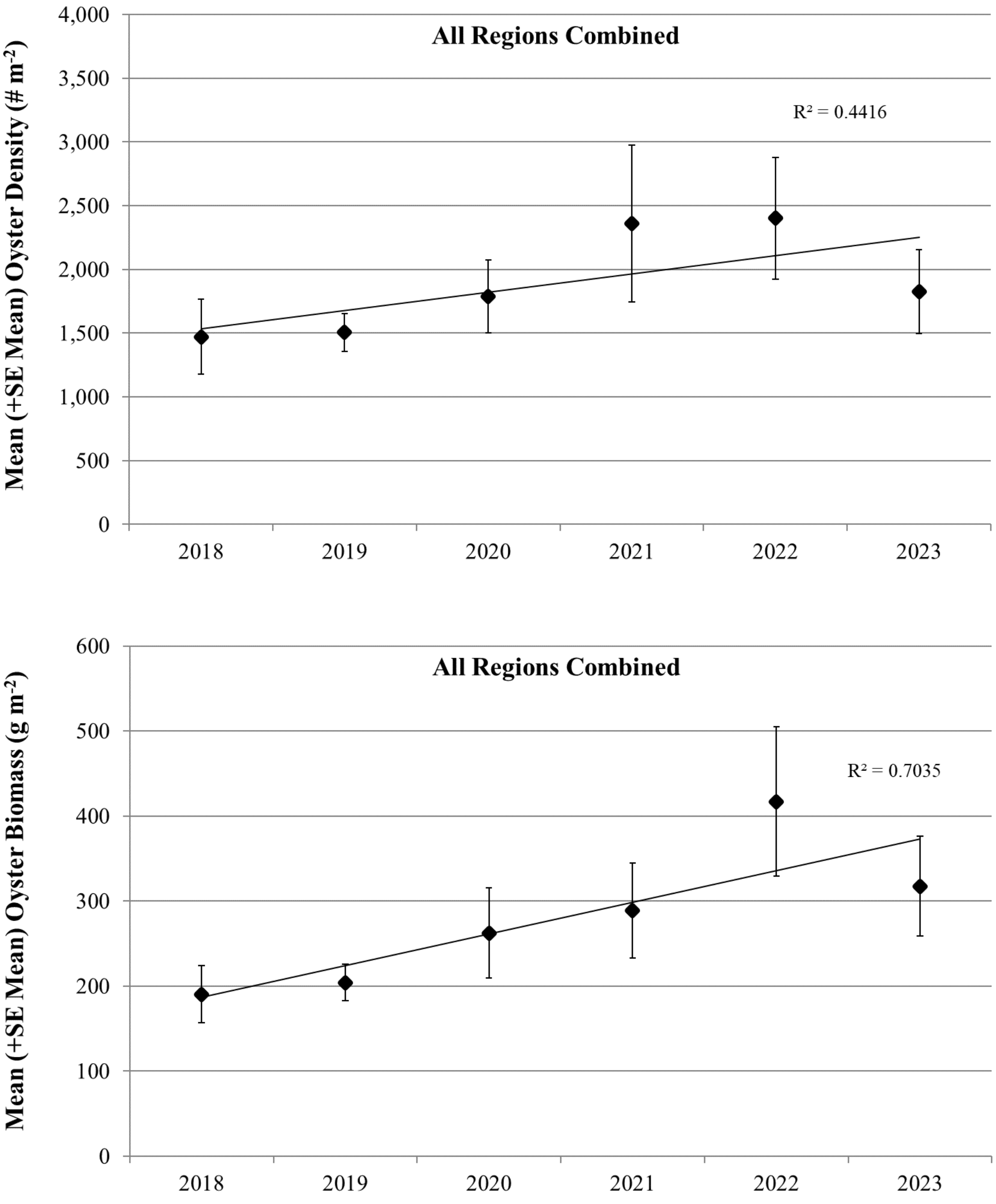
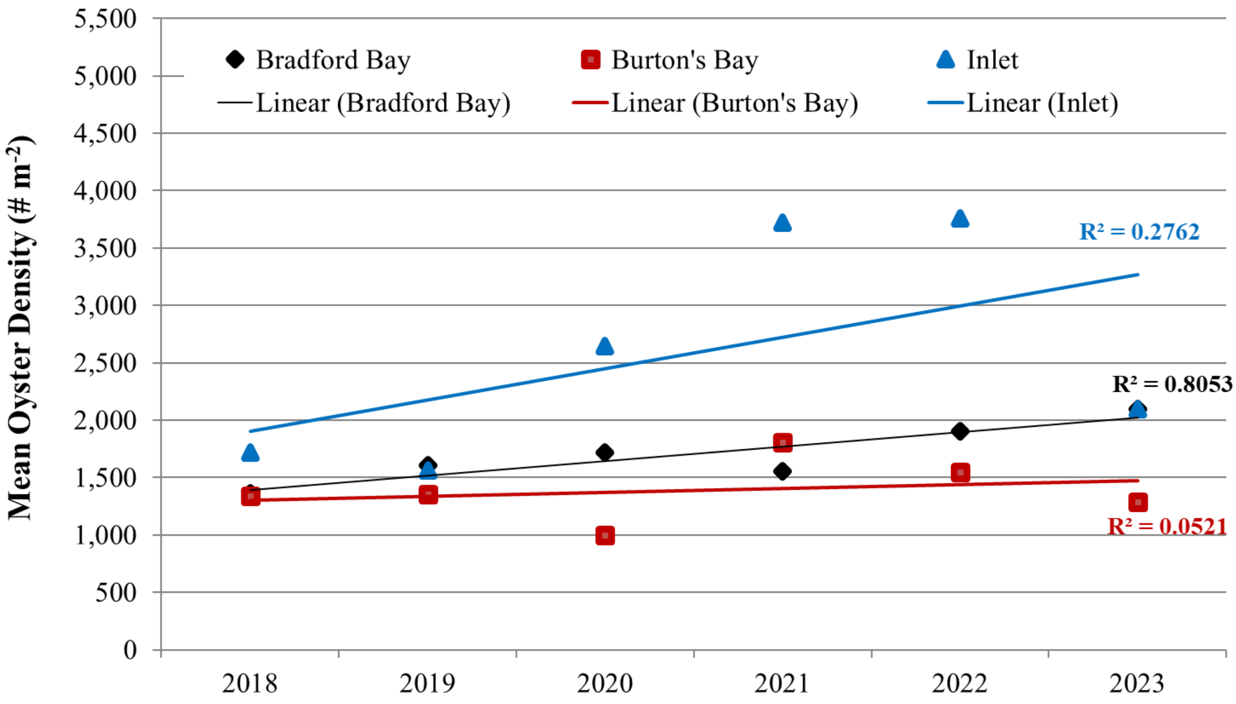


**Figure 11-4** Pooled mean (+ SE) oyster density (# m$^{-2}$) and oyster biomass (ash-free dry wt.; g m$^{-2}$) at intertidal patch reefs near Wachapreague, VA during 2018-2023. Linear regression lines are fitted to the data with the resulting R$^2$-values noted.



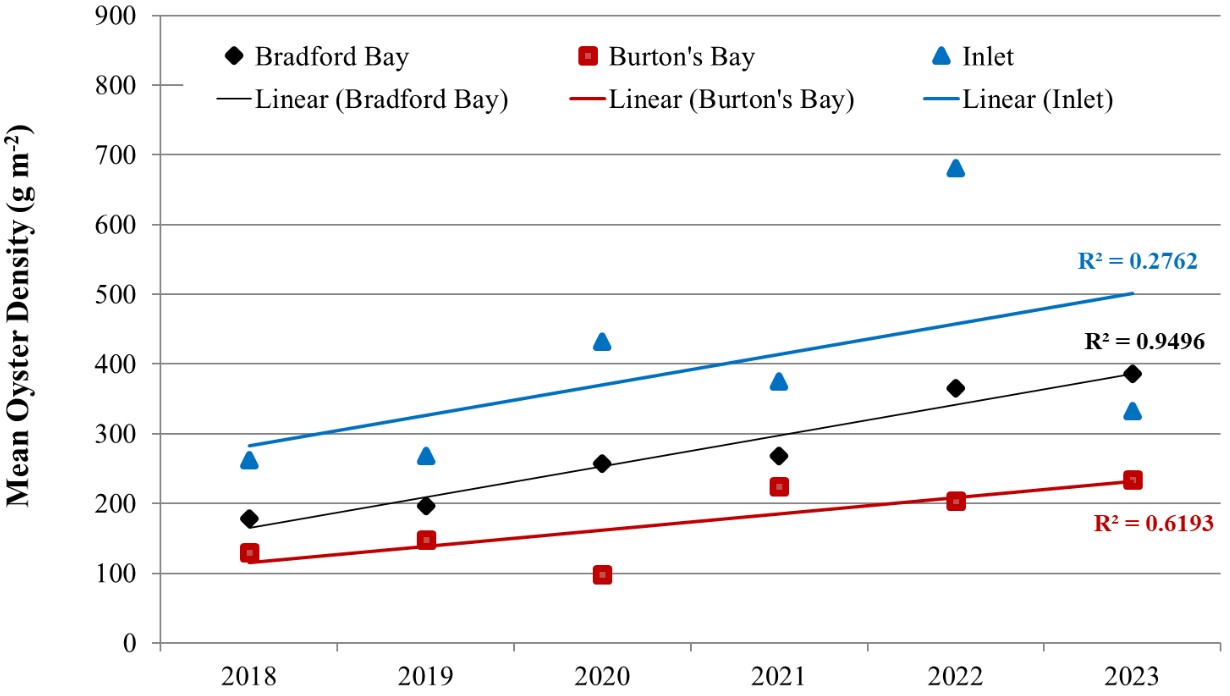


**Figure 11-5** Mean oyster density (# $m^{-2}$) and oyster biomass (ash-free dry wt.; g $m^{-2}$) at intertidal patch reefs pooled within each of 3 geographic areas near Wachapreague, VA during 2018-2023. Linear regression lines are fitted to the data with the resulting $R^2$-values noted.

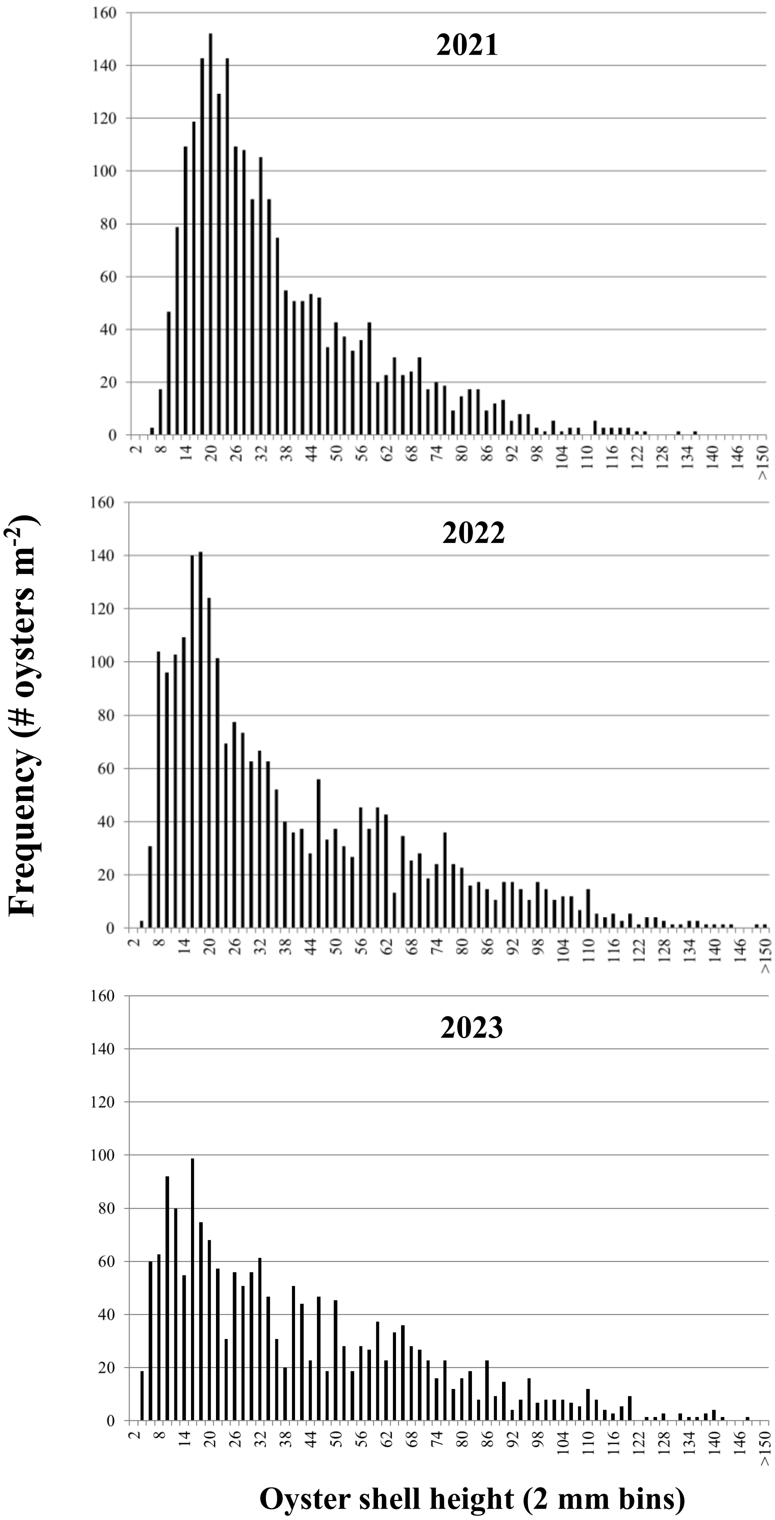


**Figure 11-6** Pooled size frequency distribution (# oysters $m^{-2}$ in 2 mm bins) of oysters found on intertidal patch reefs near Wachapreague, VA in 2020-2023 (quad n=12 each year).

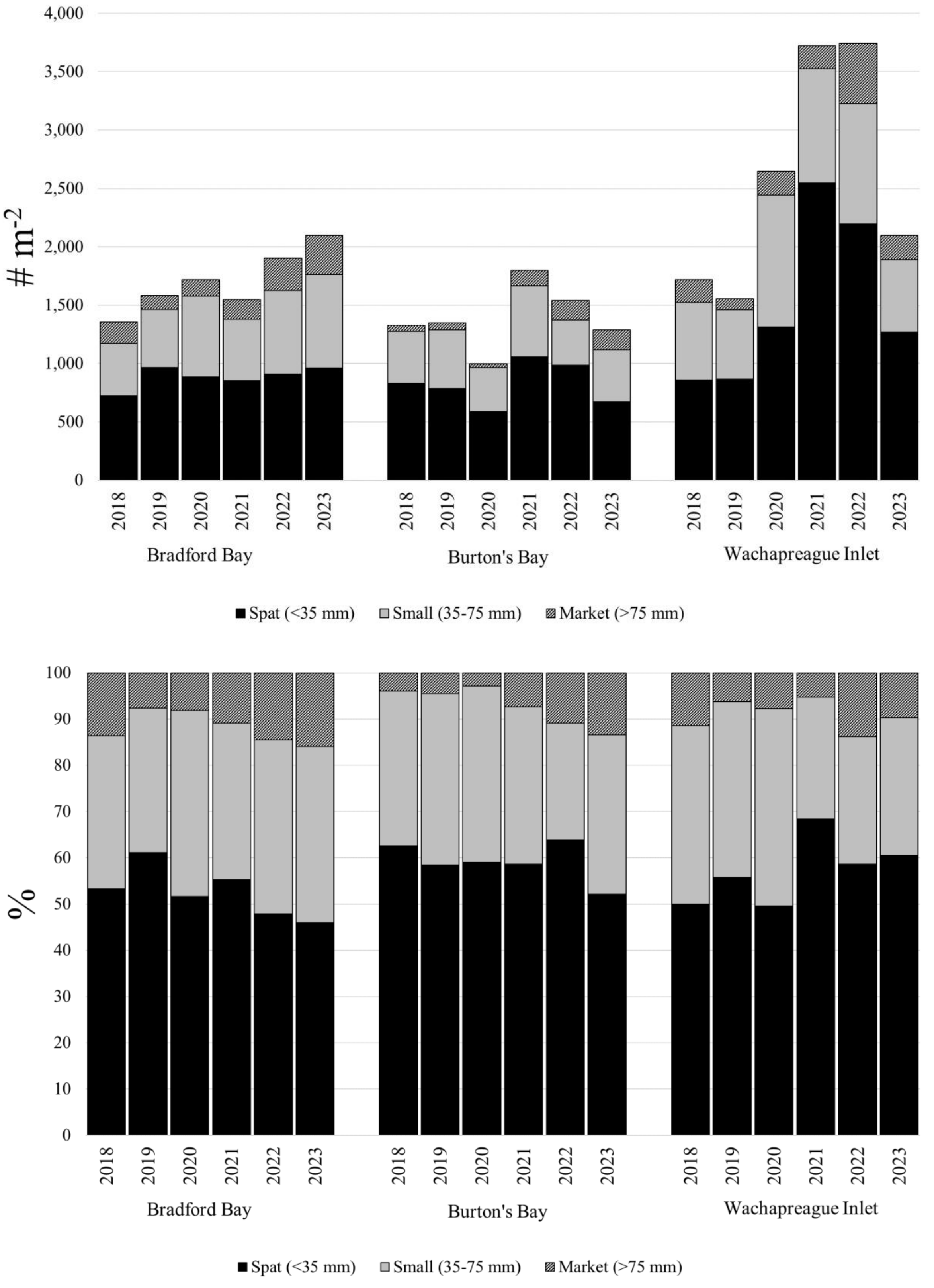


**Figure 11-7** Amount (# oysters m$^{-2}$ and %) of oysters in 3 different size classes found on intertidal patch reefs in 3 geographic areas near Wachapreague, VA during 2018-2023.

# Chapter 12. Oyster Biometrics

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### 7-year sampling plan:

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
|  |  |  | Completed | Completed | Completed |  |

### Introduction

Oyster reef health can be assessed by a variety of metrics, including oyster density (both in terms of abundance and dry tissue biomass) and size demographics (see Chapter 11). Additionally, supplementary parameters can provide a broader evaluation of the oyster population and environmental quality within a given reef system. Oyster condition index, which is highly influenced by environmental conditions, is often used as an indicator of oyster meat quality and provides a point of comparison between geographically distinct oyster populations (Abbe and Sanders 1988). Although not a direct indicator of oyster health, condition indices of ≥ 10 are typically seen in oysters of good health (Abbe and Sanders 1988). Similarly, descriptive metrics such as cup and fan ratio may be calculated from basic shell dimension measures (i.e., shell height, length, width) to provide another point of comparison between oyster reefs.

Estimation of dry tissue biomass is important for comparing populations across studies (spatially and temporally) and for potential inclusion in ecological models. However, directly estimating biomass for each oyster in a reef sample is time consuming and expensive. Therefore, developing equations that relate this to biometrics that are easier and cheaper to collect in the field (e.g., shell height) can be useful to monitoring efforts and more specific research/modeling efforts. Documenting intrannual (i.e. seasonality) and interannual patterns are important to discerning the relative confidence in utilizing such surrogates in future population estimation or ecological models.

### Study Area & Methods

Oysters were collected by hand at two intertidal sites in each of three distinct geographic areas where quadrat samples are taken annually (Fig. 12-1). All six sites were sampled on June 1 and August 25, 2023. Approximately 55 oysters from each site were collected for an estimation of a size-biomass relationship with the goal of processing 50 oysters per site. Oyster clumps were separated into single oysters, cleaned of fouling, and frozen for future processing. Shell height, length, and width (as illustrated in Fig. 12-2) were recorded to the nearest 0.01 mm using digital calipers. Condition index of individual oysters utilized the method outlined in Abbe and Sanders, (1988). For each oyster, whole wet weight was obtained to the nearest 0.001 g. Oysters were then shucked with all tissue removed from shells and placed into numbered aluminum weigh boats. Oyster tissues were dried to a constant weight at 80-100° C (~48 hrs) and oyster shells were dried at room temperature (~48 hrs). Dry tissue and dry shell mass were subsequently measured. Oyster meat condition was calculated using the following equation (Abbe and Sanders, 1988):

$$\left[\frac{Dry\ tissue\ weight\ (g)}{Shell\ cavity\ volume\ (ml)}\right] * 100$$

where shell cavity volume (ml) is equal to the difference between whole wet weight (g) and dry shell weight (g).

The standard method for loss-on-ignition (LOI) was used to derive dry tissue biomass. Individual oyster meats were dried to a constant weight at 80° C, weighed, 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. Relationships between biomass and shell height were determined through best-fit regression and graphs for spring, summer, and combined samples were produced. Observed biomass was plotted against estimated biomass provided by equations from this study, the 2021 EMP report (Ross and Snyder 2022), the 2022 EMP report (Ross and Snyder 2023) and Ross and Luckenbach (2009). A t-test was used to analyze the difference in condition index between spring and summer samples from 2023.

## 2023 Results & Discussion

Biometric data were collected on a total of 598 oysters (300 spring and 298 late-summer) that were representative of a cross-section of the sizes living on oyster reefs in the study area. Since identical sites were sampled in each of two consecutive seasons, the size distribution of oysters sampled shifted to encompass a higher frequency of slightly larger shell heights in the summer sample (Fig. 12-3). Shell height was plotted against ash free dry weight for an estimation of a size-biomass relationship in both spring ($y = 0.00003x^{2.2145}$; $R^2 = 0.7192$; Fig. 12-4) and summer samples ($y = 0.0003x^{1.6584}$; $R^2 = 0.6019$; Fig. 12-5). When combined, the following equation resulted: $y = 0.0001x^{1.9258}$ with an $R^2$ value of 0.6475 (Fig. 12-6). Although the $R^2$ value for the combined equation is lower compared to the spring sample equation, it may still provide a better general estimation of biomass since it encompasses both spring and late-summer condition oysters, which have been reported to exhibit seasonal differences in condition due to gonad development, spawning, or environmental stressors such as extreme water temperatures (Galtsoff 1964; Lawrence and Scott 1982; Paynter and Dimichele 1990).

In testing this statement against our data collected in 2023, a significant difference was detected between biomass estimations from our spring (mean AFDWT = 0.6056 +/- 0.0267) and summer (mean AFDWT = 0.4996 +/- 0.0176) sampling efforts, resulting in a $p$ value $< 0.001$ (Table 12-3). This result provides an interesting point of comparison between the two seasons given the significant reduction in estimated biomass from spring to summer regardless of the significantly greater shell height ($p = < 0.005$) reported for the summer sample (Table 12-3). Ultimately, these results reinforce the assumption of seasonality in wild oyster reefs, indicating multi-season sampling efforts are necessary in building models for biometric estimations. Further determination of a robust size-biomass relationship that encompasses seasonality will greatly reduce the sampling efforts needed to estimate future wild oyster production in Virginia's seaside coastal bays. In addition to saving time and resources, destructive sampling would also be minimized, allowing sampled oysters to continue providing ecosystem services.

For a measure of oyster meat quality, condition index may be used, where greater numbers indicate greater shell fullness and more plump meats. This can provide a measurable surrogate for overall oyster health; however, it is known that oyster condition exhibits temporal variation due to gametogenesis and subsequent spawning. Samples from June and August 2023 were used to compare condition indices between oysters preparing to spawn or actively spawning and oysters in the late summer post-spawn condition. There was a significant decrease in oyster meat condition between the spring (mean CI = 7.79 +/- 0.24) and late summer (mean CI = 6.68 +/- 0.11) sampling periods with all sites averaged together ($p < 0.00003$), although the magnitude of change was variable between individual sites (Table 12-1). This provides additional evidence that oysters exhibit seasonal differences in meat condition in Virginia's seaside coastal bays. It is important to note that these results are directly correlated with biomass estimations above, as both equations share a variable in their determination (dry meat weight). Descriptive shell metrics of cup and fan ratio were recorded during the condition indexing process; however, they are not reported within this chapter. These data are available upon request.

## Comparison to Previous Years

Estimates of oyster size-biomass relationships within the ecological monitoring program were completed in 2021, 2022 and 2023 (Ross and Snyder 2022; Ross and Snyder 2023). In addition to oyster biometric sampling conducted in 2021 and 2022, we also compared biomass estimations and size-biomass equations from this year's samples to a previous study of oysters in a larger geographic area (Ross and Luckenbach 2009).

Further comparing the four equations, the estimated biomass from each were plotted against our observed biomass data from 2023 (Fig. 12-8). This figure provides a good illustration of the variation between our 2023 data and the predictions from each study. Equations generated from sampling efforts in 2021 to present each provide a flatter trajectory for estimated biomass in relation to increased shell height when compared to the equation from Ross and Luckenbach (2009), which demonstrates a lower estimation of the test data set at lower oyster size and exhibits a steeper increase in estimated biomass as shell height increases. The quantity of data points at the lower and higher ends of the data that power functions are derived from can greatly affect the resulting equations and trendlines, especially at the tails. The increased sample size of the 2009 data set likely impacts the visual differences of the curves (Fig. 12-8). Alternatively, or additionally, differences may also be due to the timing of sampling efforts conducted in Ross and Luckenbach (2009), which took place during the winter and spring, encompassing oysters that are conditioned for dormancy through winter and preparing for the spring spawning season by increasing gonadal development. In contrast, biometric sampling for both 2022 and 2023 incorporated spring and summer oyster samples, where summer samples exhibited reduced mean biomass in both cases, even though mean shell height shifted to be slightly larger in summer samples (Table 12-3; Fig. 12-3).

To provide a practical comparison of the dataset-specific size-biomass relationships noted above, the size-biomass equation provided from each source was applied to this year's combined shell heights for a total of 598 individual oysters. The resulting estimated biomass was then totaled and compared to the actual total biomass measured this year, with differences reported as percentages (Table 12-2). The lowest difference between the estimated and actual biomass totals was provided by the 2021-2023 combined equation, which underestimated the observed total biomass by just 0.1%. The next closest was Ross and Luckenbach (2009), which overestimated by 4.3%, followed by our source data equation which underestimated biomass by 4.4%, and lastly by the 2022 equation (see Chapter 12 from Ross and Snyder 2023) that underestimated biomass by 4.7%. The 2021-2023 combined equation is the most accurate, likely because it is made up of a higher number of samples (*n* = 1,443) than the other single-year EMP datasets. In comparison, Ross and Luckenbach (2009) had a much larger sample size and these were spread along an expanded geographic region. Additionally, sampling was conducted at a different time of year, from December of 2007 to June of 2008. Biometric dynamics within these reefs may have changed since this study, although the resulting equation is still more accurate than our individual year source equations. These results suggest that our oyster size-biomass relationship for the Wachapreague area that combines 2021-2023 data is an appropriate model for estimating biomass via shell height in the environs near Wachapreague. It also supports the continued utility of the 2009 equation for use anywhere in the Virginia seaside coastal lagoons. In any case, the fact that all of these models are within 5% of the actual total biomass of a known sample of oysters suggest that these equations can be utilized to estimate biomass based on oyster shell height in lieu of processing individual oyster to directly measure biomass. Of course, whether oyster biomass is actually measured or calculated from shell height will be dependant on the desired resolution of this metric in a given research or monitoring study.

Condition index values were similar to those reported last year, however there were some differences between sites, where some increased and some decreased in comparison to 2022 (Table 12-1). Similar to last year, overall condition index generally decreased between spring and summer, indicating a seasonal difference in meat condition, however this was not consistent across all sites sampled in 2023. Interestingly, summer condition evaluated in 2023 was generally greater than in 2022 at all but one site. These slight differences could be an indication of interannual variation in meat condition caused by natural flux in weather patterns or a change in competition for food resources on a given reef, for example.

The data presented here provide an example of how long-term datasets may be useful tools for future scientific endeavors. With the accumulation of data since 2021 and relative success in estimating biomass given shell length of the resulting equation presented here, sampling will be shifted from annual to biennial with the next sampling event taking place in 2025.

## 2023 Acknowledgements

We would like to thank Edward Smith, Emory Harned, Macy Richardson, Carter Nottingham, Oscar Melendez Vera, and Hunter Rippon for field and lab processing assistance.

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**Table 12-1.** Average condition index (CI, +/- SE) and sample size (*n*) recorded at individual sites and combined study areas near Wachapreague, VA since 2021.

| **Study Area** | **Site** | **2021** | | **2022** | | | | **2023** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Spring** | | **Late-Spring** | | **Late-Summer** | | **Late-Spring** | | **Late-Summer** | |
| | | **CI (SE)** | ***n*** | **CI (SE)** | ***n*** | **CI (SE)** | ***n*** | **CI (SE)** | ***n*** | **CI (SE)** | ***n*** |
| Bradford Bay | 1 | 9.06 (0.50) | 18 | 6.83 (0.25) | 50 | 5.50 (0.25) | 50 | 5.90 (0.32) | 50 | 6.71 (0.26) | 50 |
| | 2 | 10.43 (0.62) | 32 | 6.61 (0.26) | 50 | 5.68 (0.16) | 50 | 8.46 (0.39) | 50 | 6.73 (0.25) | 49 |
| | *All* | *9.94 (0.45)* | *50* | *6.72 (0.18)* | *100* | *5.59 (0.15)* | *100* | *7.18 (0.28)* | *100* | *6.72 (0.18)* | *99* |
| Burton's Bay | 4 | 9.97 (0.38) | 66 | 6.91 (0.34) | 50 | 5.87 (0.17) | 50 | 8.00 (0.34) | 50 | 6.08 (0.22) | 49 |
| | 5 | 10.58 (0.42) | 43 | 10.74 (0.32) | 50 | 6.47 (0.16) | 50 | 6.99 (0.38) | 50 | 6.28 (0.22) | 50 |
| | *All* | *10.21 (0.28)* | *109* | *8.82 (0.24)* | *100* | *6.17 (0.12)* | *100* | *7.50 (0.26)* | *100* | *6.18 (0.16)* | *99* |
| Wach. Inlet | 7 | 10.88 (0.40) | 35 | 10.05 (0.38) | 50 | 6.06 (0.61) | 50 | 10.36 (1.08) | 50 | 6.63 (0.25) | 50 |
| | 9 | 9.03 (0.36) | 52 | 9.35 (0.35) | 50 | 5.86 (0.20) | 50 | 7.05 (0.44) | 50 | 7.65 (0.33) | 50 |
| | *All* | *9.77 (0.29)* | *87* | *9.70 (0.26)* | *100* | *5.96 (0.32)* | *100* | *8.71 (0.60)* | *100* | *7.14 (0.21)* | *100* |
| Combined EMP Area | *All* | *10.00 (0.18)* | *246* | *8.00 (0.15)* | *300* | *5.96 (0.12)* | *300* | *7.79 (0.24)* | *300* | *6.68 (0.11)* | *298* |

**Table 12-2.** Comparison of estimated biomass (ash-free dry tissue weight, g) from various equations and percent difference from the actual measured 2023 biomass.

| Equation source | Equation | Estimated Biomass (g) | Difference from Measured (%) |
|---|---|---|---|
| Measured 2023 Biomass | ----- | 331 | ----- |
| Pooled 2023 Oysters | $y=0.0001x^{1.93}$ | 316 | -4.4 |
| Pooled 2022 Oysters | $y=0.0004x^{1.62}$ | 315 | -4.7 |
| Ross and Luckenbach (2009) | $y=0.00001x^{2.45}$ | 345 | 4.3 |
| Pooled 2021-2023 Oysters | $y=0.0001x^{1.94}$ | 330 | -0.1 |

**Table 12-3.** Comparison of mean biomass (g, +/- SE), mean shell height (mm +/- SE), and sample size between 2022 and 2023 sampling events.

| Sampling period | Mean observed biomass (g, SE) | Mean shell height (mm, SE) | *n* |
|---|---|---|---|
| Spring 2022 | 0.7312 (0.0305) | 84.22 (1.36) | 300 |
| Summer 2022 | 0.5891 (0.0178) | 91.01 (1.38) | 300 |
| Spring 2023 | 0.6056 (0.0267) | 78.99 (1.56) | 300 |
| Summer 2023 | 0.4996 (0.0176) | 85.00 (1.44) | 298 |

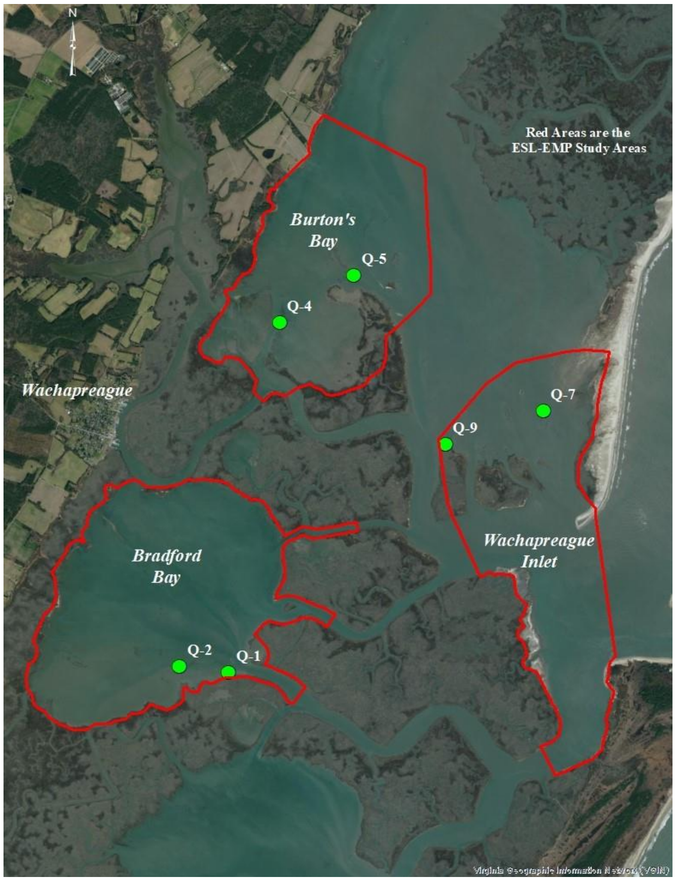

**Figure 12-1** Locations of 6 intertidal oyster reef monitoring sites near Wachapreague, VA during 2023 (red polygons denote the ESL-EMP study areas).

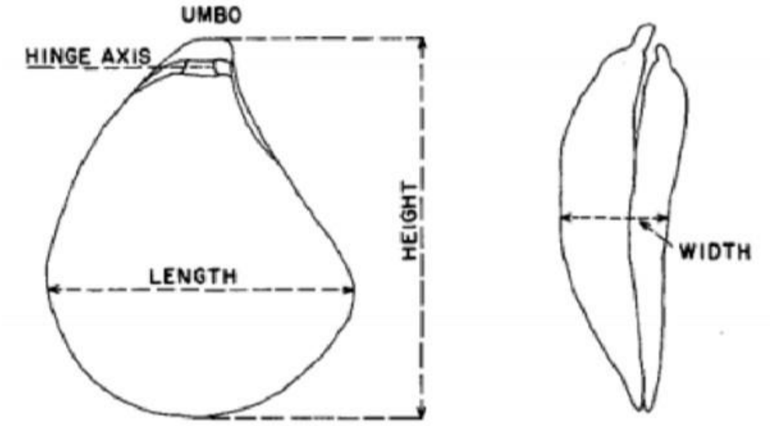

**Figure 12-2** Visual representation of shell dimensions used to determine size-biomass relationships (Galtsoff, 1964).

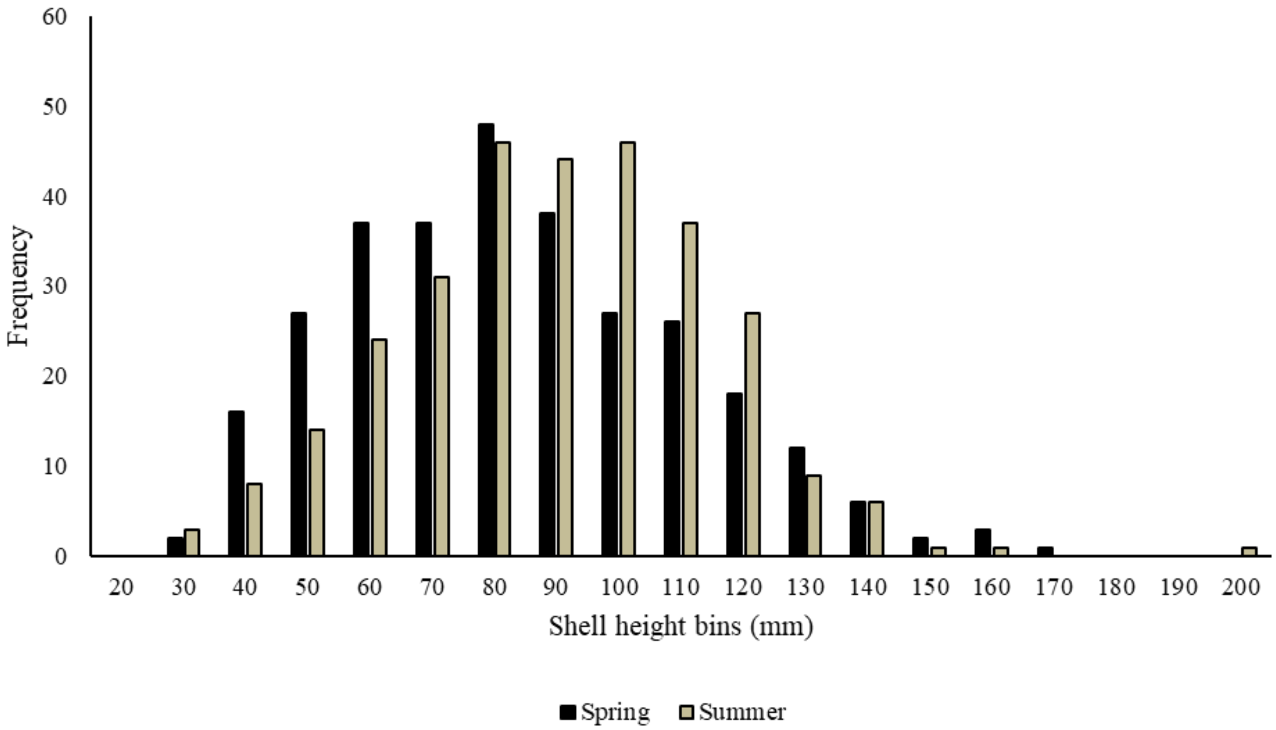

**Figure 12-3** Size frequency distribution (# oysters in 10 mm bins) of oysters from spring and summer samples found on intertidal patch reefs near Wachapreague, VA in 2023 (spring n=300; summer n=298).

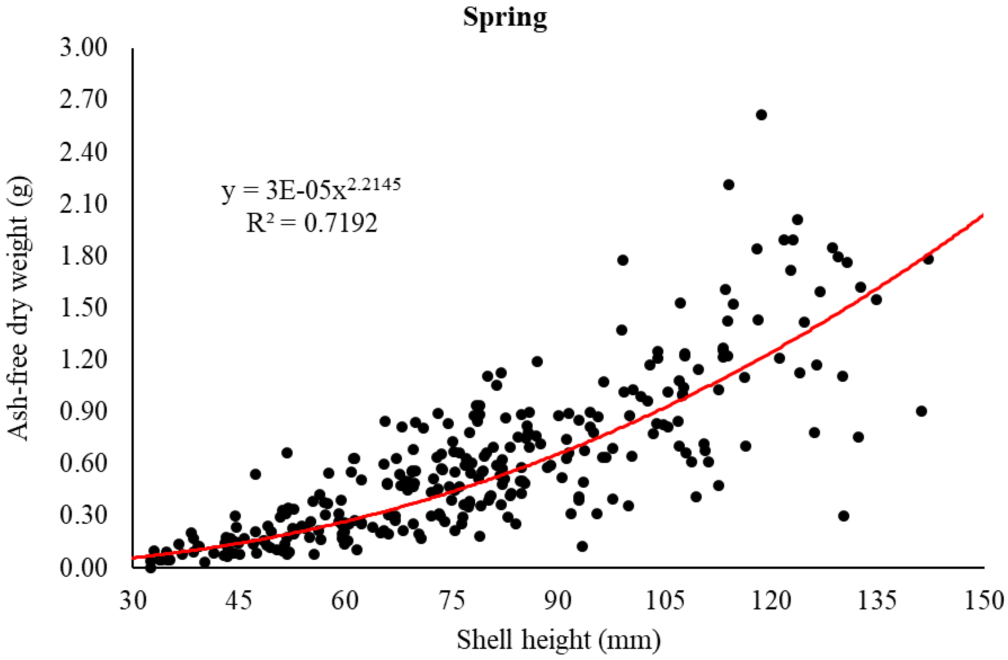

**Figure 12-4** Graphical output of best-fit power regression used for estimation of an oyster shell height (mm) vs. dry tissue biomass (g) relationship for the spring sample in 2023.

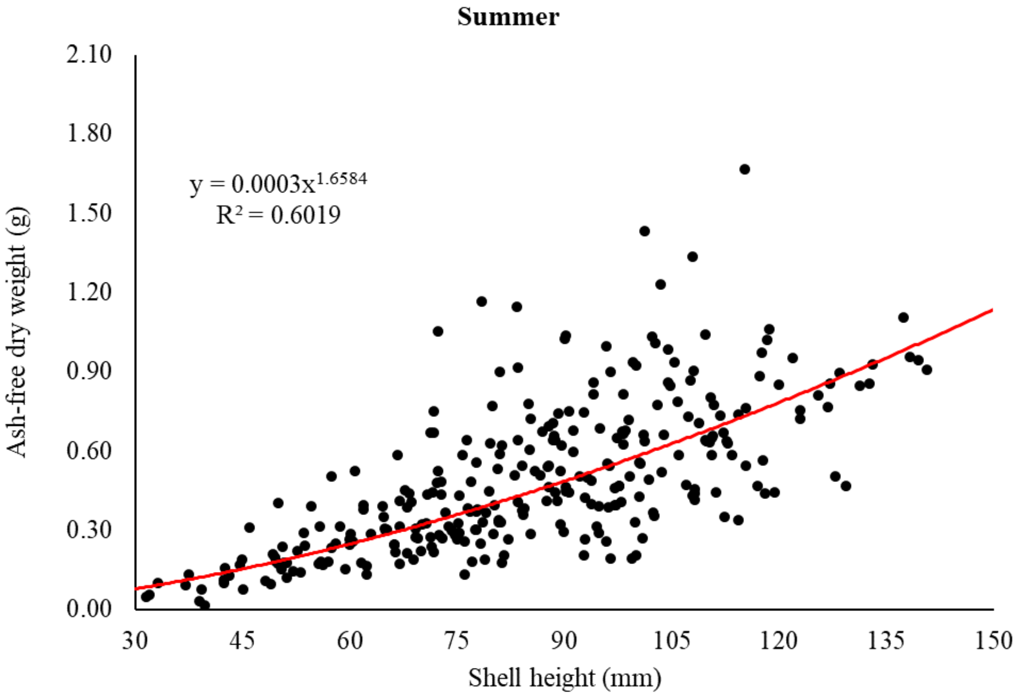

**Figure 12-5** Graphical output of best-fit power regression used for estimation of an oyster shell height (mm) vs. dry tissue biomass (g) relationship for the summer sample in 2023.

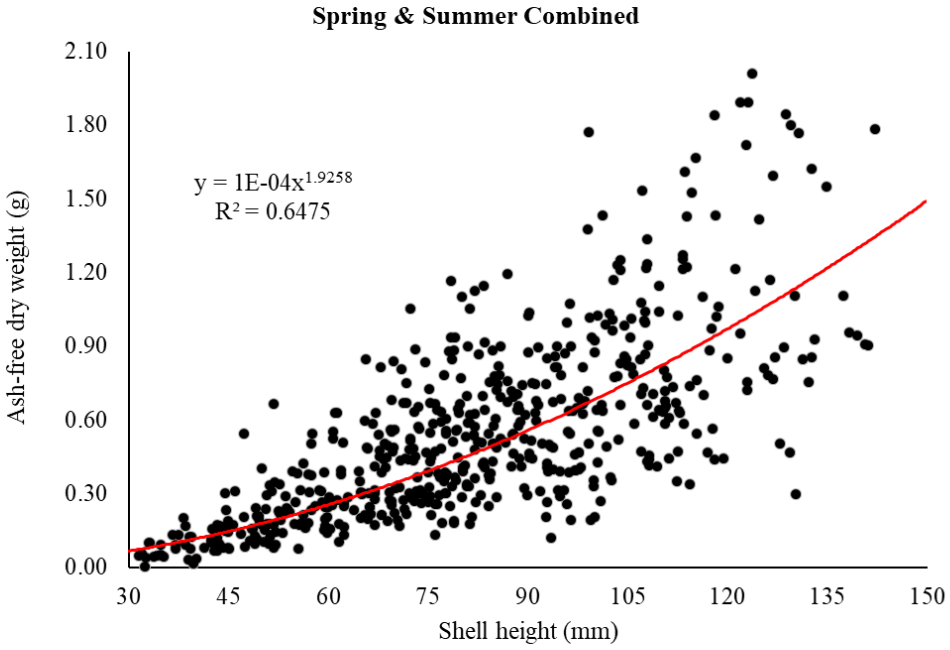

**Figure 12-6** Graphical output of best-fit power regression used for estimation of an oyster shell height (mm) vs. dry tissue biomass (g) relationship for combined sampling efforts in 2023.

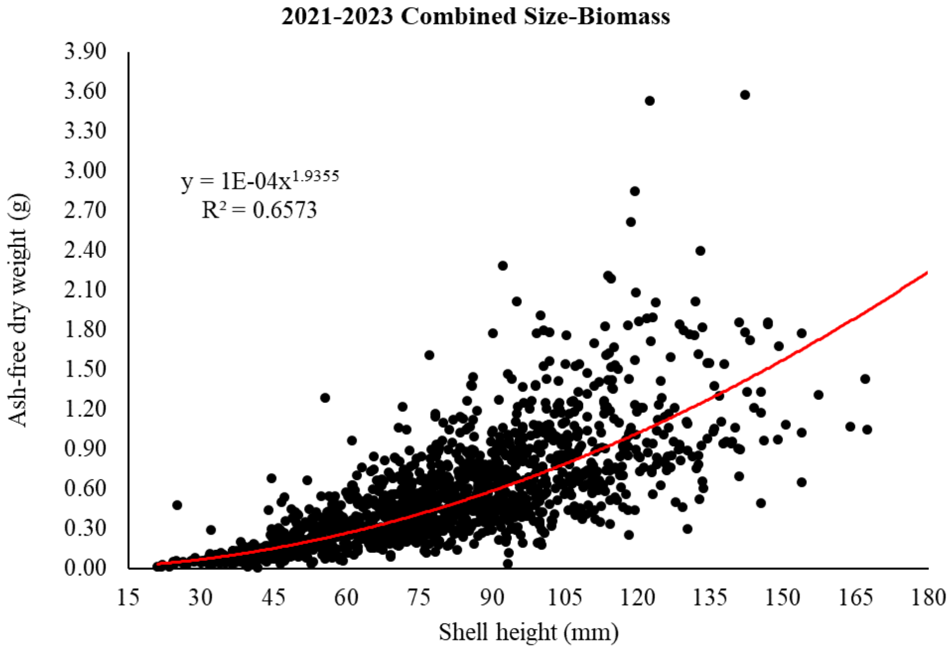

**Figure 12-7** Graphical output of best-fit power regression used for estimation of an oyster shell height (mm) vs. dry tissue biomass (g) relationship for combined sampling efforts from 2021-2023.

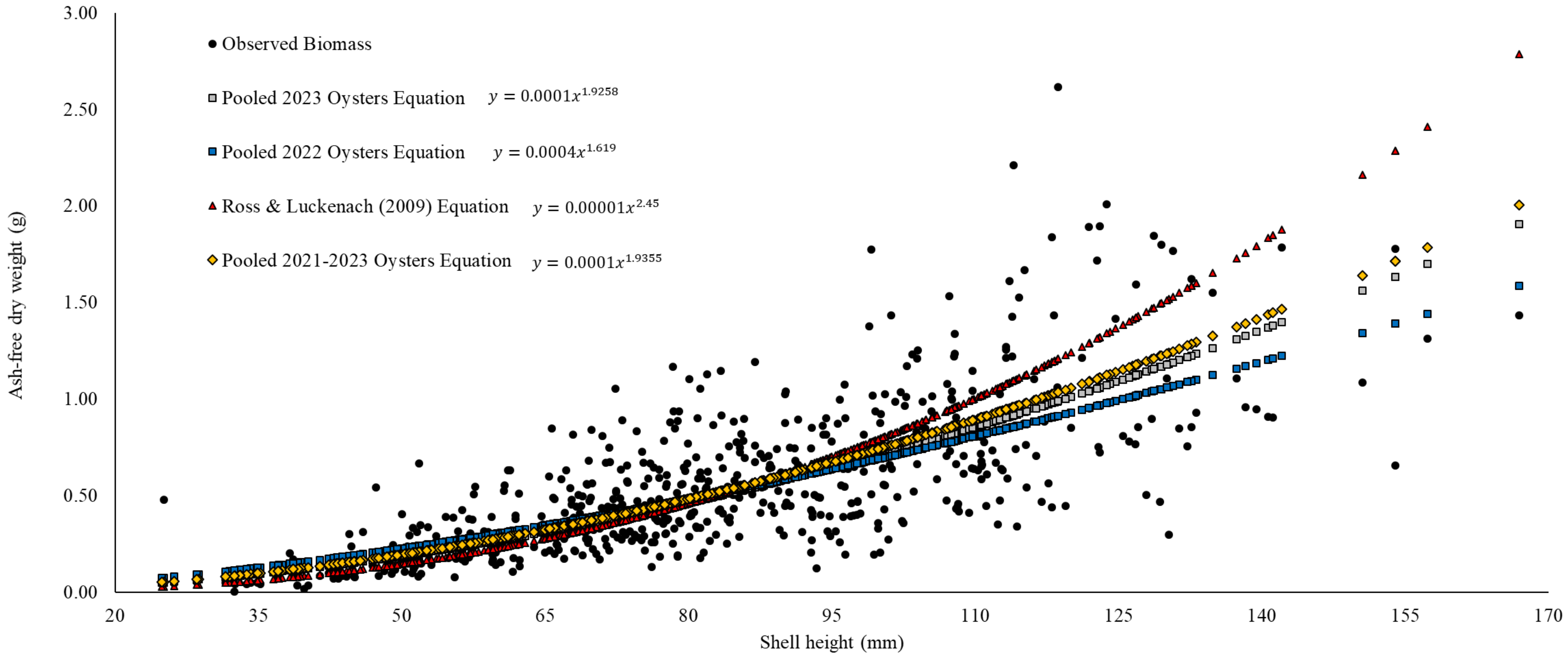

**Figure 12-1** Comparison between observed biomass (AFDWT) and predicted biomass from equations provided in this study, the 2021 EMP report (see Chapter 12, Ross and Snyder, 2022), and Ross and Luckenbach (2009).

# Chapter 13. Hard Seabed Epi-benthic Community

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Complete | | 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 and 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 11) 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 Status

Work on this parameter was not planned for 2023. We plan to continue monitoring this area in 2024. Methodology and data from 2022 can be found here: https://scholarworks.wm.edu/reports/2849/

Ross, P. G., and Snyder, R. A. (2023) Ecological Monitoring Program at VIMS ESL: Annual report 2022. VIMS Eastern Shore Laboratory Technical Report No. 11. Virginia Institute of Marine Science, William & Mary. https://doi.org/10.25773/pc3t-me16

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Ross, P.G. and M. W. Luckenbach. 2009. Population assessment of Eastern oysters (Crassostrea virginica) in the seaside coastal bays. Final report submitted to NOAA-Va Coastal Zone Management Program. 101 pp.

# Chapter 14. Soft Seabed Benthic Community

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### 7-year sampling plan:

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| Complete | Complete | Complete | Complete | Partial | Complete | |

## 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). In addition to previous sample sites within the coastal lagoon system, in 2022 we added samples in the near shore surf zones on the ocean side of Cedar and Paramore islands.

The distribution and abundance of these species assemblages is also of importance for educators and researchers visiting VIMS ESL. While there is considerable primary production from benthic micro and macro algae on the benthic surfaces of this coastal system, this chapter will focus primarily on the benthic macroinvertebrates. In addition to tracking status and trends in the benthic communities of the coastal environment, the information can be used in planning and enriching education activities, and provides an environmental context for research proposals, experimental designs, and interpretation of research results.

## Study Area & Methods

A Smith-McIntyre grab sampler (Fig. 14-1) was utilized in 2023 to collect benthic macrofauna. The grab sampled a 0.0841 m$^2$ area to a depth of 10-15 cm. In previous years, grab samples at 36 sites were distributed in three geographic areas. However, in 2023, we reduced the number of sites to 27 of these original 36 locations (Fig. 14-2) due to logistical constraints. We plan to transition to biennial sampling for this metric moving forward starting in 2024. These sites were stratified 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, although these samples are pooled together for current reporting. All samples in the 3 original study areas were collected between May 22-24, 2023. In addition to this effort, we also sampled six sites in the ocean off of Cedar and Parramore islands that we started sampling in 2022 (Fig 14-2). The six ocean samples were collected on June 9. Data for these ocean sites are not reported here. If we decide to continue sampling those moving forward, we will include all the 2022 and 2023 data at that time.

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 and 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 80° 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.

During 2018-2023, we have been adjusting the number of sites sampled and the gear used. In previous reports, summary data was presented that included all of the samples within a given year. In this report we have transitioned to just including data from the final 27 sites we have selected as sentinels moving forward. Please note, therefore, that some overall and geographic area-specific summary data will differ compared to previous reports. We have to do this as we prepare to start analyzing trends in this data and focus on the final 27 sites. Prior to 2020, samples within these areas consisted of a combination of infaunal cores and grab samples, but have been sampled exclusively by grab samples since (Table 14-1).

## 2023 Results & Discussion

In total, 1,218 individual organisms were sampled representing ~70 genera. The total ash-free dry biomass of the organisms collected was 15.1 g (Table 14-2). In 2023, polychaetes, amphipods, bivalves and snails dominated by density (# $m^{-2}$, Table 14-3), while snails, polychaetes and bivalves dominated in terms of biomass (g $m^{-2}$; Table 14-4). Various differences in the biomass density of broad taxa were observed between the EMP study areas (Table 14-5).

Density data by genus (pooled for all three geographic areas) are summarized in Table 14-6. This table is not fully inclusive for previous years; to be included in this table, a taxon must be present in more than one previous year or in the current sampling year. See previous annual reports for more information. Basic community metrics such as taxa richness and Shannon Diversity Index were similar between study areas for 2023 (Table 14-7).

## Comparison to Previous Years

There was a decrease in the overall density of organisms (# $m^{-2}$) collected relative to 2021 and this year was more similar to 2018 and 2019 in this respect (Table 14-3). Additionally, we saw a decrease the dry tissue biomass (g $m^{-2}$) collected in samples (Table 14-4). Most of these declines were observed in macroalgae in all areas and macrofauna specifically in the Inlet area (Table 14-5; Figs. 14-3 and 14-4). Two macrofaunal taxa contributed to the majority of these decreases: the amphipod *Ampelisca* and the bivalve *Ensis* (Table 14-6). Part of that is likely attributable to interannual variation (see below for a discussion for *Ensis*) and natural variation at specific sites. The patchy nature of the distribution of these organisms also has a potential impact on annual fluctuations in sampling. Longer term trends in population dynamics of coastal macrofauna can be driven by large scale climatic patterns, such as the North Atlantic Oscillation (NAO; MacKenzie and Tarnowski, 2018) and overall climate change. These types of dynamics are only resolved by building long term datasets.

As noted above, there were some noticeable differences for some taxa (e.g. *Ensis* and amphipods) while others remained very similar (e.g., polychaetes; Tables 14-3 and 14-4). For specific taxa, an example of an interesting find from 2018-2023, is a change in the number of the bivalve *Ensis leei* (Table 14-6). Interestingly, the bulk of this increase and subsequent decrease occurred in the Wachapreague Inlet area and, to a much lesser extent, the Burton’s Bay area (Fig. 14-5). Additionally, this increase in density in 2020-2021 appears to be related to high recruitment in 2020 as demonstrated by the annual size frequency distribution (Fig. 14-6) and is mainly composed of small sized individuals. It appears that the large number of recruits have not persisted into 2023 and recruitment since 2020 has not been high. With additional years of data to examine trends and annual differences, we will also provide more in-depth statistical analyses.

Most of the information presented in this report is very basic summary data. However, there is the opportunity to explore temporal and spatial patterns in more detail. For example, it is apparent that some representative taxa (e.g., polychaete *Allita*, amphipod *Ampelisca* and bivalve *Ensis*) are not evenly distributed around the Wachapreague environs nor within specific study areas (Fig. 14-7). We expect this to be the case for many taxa. Eventually, discerning any changes in the distributional patterns over time is one of the major goals of this monitoring program.

## 2023 Acknowledgements

We would like to thank Sean Fate, Edward Smith, Oscar Melendez Vera, and Hunter Rippon and for field and lab processing assistance.

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**Table 14-1**. Soft-sediment community sampling plan within three regions near Wachapreague, VA during 2018-2023 (went to bienniel sampling after 2021). Just samples in the current 27 sentinel sites.

| | | **2018** | | **2019** | | **2020** | **2021** | **2023** |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Sub-habitat** | **# Grab Samples** | **# Core Samples** | **# Grab Samples** | **# Core Samples** | **# Grab Samples** | **# Grab Samples** | **# Grab Samples** |
| Bradford Bay | Intertidal | 2 | 1 | 2 | 1 | 3 | 3 | 3 |
| | Shallow Subtidal | 2 | 1 | 3 | 0 | 3 | 3 | 3 |
| | Deep/Channel Edge | 3 | 0 | 3 | 0 | 3 | 3 | 3 |
| Burton's Bay | Intertidal | 2 | 1 | 2 | 1 | 3 | 3 | 3 |
| | Shallow Subtidal | 2 | 1 | 3 | 0 | 3 | 3 | 3 |
| | Deep/Channel Edge | 2 | 1 | 2 | 1 | 3 | 3 | 3 |
| Wach. Inlet | Intertidal | 2 | 1 | 2 | 1 | 3 | 3 | 3 |
| | Shallow Subtidal | 3 | 0 | 3 | 0 | 3 | 3 | 3 |
| | Deep/Channel Edge | 2 | 1 | 2 | 1 | 3 | 3 | 3 |
| *Total* | | *20* | *7* | *22* | *5* | *27* | *27* | *27* |

**Table 14-2**. Summary of the total # and biomass (ash-free dry wt., g) of individuals collected for broad taxa sampled in 27 soft-sediment samples near Wachapreague, VA during late-spring/early-summer 2023. A "+" indicates presence of a taxa, typically those where counting individuals is impractical.

| Category | Common Name | Taxonomic Grouping | Total # | Total Biomass (g) |
|---|---|---|---|---|
| ***All Taxa*** | | | *1,218* | *15.0600* |
| **Macroalgae** | Seaweeds | Macroalgae | + | 0.8797 |
| **Vascular plant** | Sea grass | Vascular plant | + | 1.2572 |
| **Worms** | Polychaete worms | Polychaeta | 415 | 3.5547 |
| | Ribbon worms | Nemertea | 1 | 0.0226 |
| **Mollusks** | Snails | Gastropoda (snails) | 141 | 3.6607 |
| | Clams/mussels | Bivalvia (non-Crassostrea) | 176 | 2.6399 |
| **Crustaceans** | Hermit crabs | Paguridae | 14 | 0.1564 |
| | Amphipods | Amphipoda | 401 | 0.0764 |
| | Isopods | Isopoda | 9 | 0.0191 |
| | Mud Crabs | Pleocyemata (Xanthidae) | 15 | 0.6914 |
| | Shrimp | Pleocyemata (Caridea) | 10 | 0.1171 |
| | Burrowing shrimp | Pleocyemata (Axiidea) | 7 | 0.0112 |
| | Pea crabs | Brachyura (Pinnotheridae) | 10 | 0.0992 |
| | Mantis shrimp | Stomatopoda | 1 | 0.3851 |
| | Cumaceans | Malacostraca (Cumacea) | 4 | 0.0003 |
| | Bony Fish | Pleocyemata (Ovalipes) | 1 | 0.1521 |
| | Sea cucumbers | Balanidae | 2 | 0.0043 |
| | Fiddler crabs | Pleocyemata (Ocypodidae) | 8 | 1.3290 |
| | Mysids | Malacostraca (Mysida) | 1 | 0.0006 |
| **Other Animals** | Fly larvae | Diptera | 2 | 0.0030 |

**Table 14-3**. Summary of the total density (#/m$^2$) of common broad taxa collected in 27 soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2023. A "+" indicates presence of a taxon, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon. To be included in this table, a taxon must be present in more than one previous year or in the current sampling year.

| Category | Common Name | Taxonomic Grouping | 2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|---|---|
| ***All Taxa*** | | | *468.2* | *629.6* | *975.0* | *1,364.3* | *536.4* |
| **Macroalgae** | Seaweeds | Macroalgae | + | + | + | + | + |
| **Vascular plant** | Sea grass | Vascular plant | | | + | | + |
| **Worms** | Polychaete worms | Polychaeta | 282.8 | 229.9 | 230.8 | 172.2 | 182.8 |
| | Ribbon worms | Nemertea | 1.2 | 0.5 | 1.3 | | 0.4 |
| **Mollusks** | Snails | Gastropoda (snails) | 66.9 | 107.2 | 89.8 | 42.3 | 62.1 |
| | Clams/mussels | Bivalvia (non-Crassostrea) | 29.3 | 98.1 | 285.4 | 495.0 | 77.5 |
| | Slipper shells | Gastropoda (slipper shells) | 0.6 | 0.5 | 0.9 | | |
| **Crustaceans** | Hermit crabs | Paguridae | 2.3 | 4.3 | 5.7 | 4.0 | 6.2 |
| | Amphipods | Amphipoda | 67.5 | 136.1 | 301.2 | 604.2 | 176.6 |
| | Isopods | Isopoda | 5.3 | 17.7 | 9.2 | 10.1 | 4.0 |
| | Mud crabs | Pleocyemata (Xanthidae) | | 9.1 | 11.5 | 1.3 | 6.6 |
| | Shrimp | Pleocyemata (Caridea) | 1.8 | 9.1 | 8.4 | 3.1 | 4.4 |
| | Burrowing shrimp | Pleocyemata (Axiidea) | 0.6 | 5.4 | 11.9 | 7.0 | 3.1 |
| | Pea crabs | Brachyura (Pinnotheridae) | 1.8 | 1.1 | 10.6 | 18.9 | 4.4 |
| | Other shrimp | Pleocyemata | 1.8 | | 0.4 | | |
| | Mantis shrimp | Stomatopoda | 0.6 | | | | 0.4 |
| | Cumaceans | Malacostraca (Cumacea) | | 0.5 | 1.8 | 1.3 | 1.8 |
| | Lady crabs | Pleocyemata (Ovalipes) | | | | | 0.4 |
| | Barnacles | Balanidae | | | | | 0.9 |
| | Fiddler crabs | Pleocyemata (Ocypodidae) | | | | | 3.5 |
| | Mysids | Malacostraca (Mysida) | | | | | 0.4 |
| **Other Animals** | Bony Fish | Osteichthyes | 1.8 | 1.1 | 0.4 | 0.9 | |
| | Sea cucumbers | Echinodermata (sea cucumber) | | 1.1 | 0.9 | | |
| | Hemichordates | Hemichordata | 1.2 | 1.1 | | | |
| | Fly larvae | Diptera | | 0.5 | 0.9 | 2.6 | 0.9 |
| | Anemones | Cnidaria (Actiniaria) | 2.3 | 0.5 | 1.8 | 0.9 | |

**Table 14-4**. Summary of the total biomass (ash-free dry wt., g/m2) of common broad taxa collected in 27 soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2023. A blank cell indicates the absence of that taxon. To be included in this table, a taxon must be present in more than one previous year or in the current sampling year.

| Category | Common Name | Taxonomic Grouping | 2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|---|---|
| ***All Taxa*** | | | *8.6535* | *14.5939* | *13.4859* | *8.9918* | *6.6323* |
| **Macroalgae** | Seaweeds | Macroalgae | 3.7952 | 2.9231 | 1.7622 | 3.1418 | 0.3874 |
| **Vascular plant** | Sea grass | Vascular plant | | | 1.4786 | | 0.5537 |
| **Worms** | Polychaete worms | Polychaeta | 2.9135 | 2.0847 | 2.0960 | 1.7156 | 1.5655 |
| | Ribbon worms | Nemertea | 0.2127 | 0.0053 | 0.0807 | | 0.0100 |
| **Mollusks** | Snails | Gastropoda (snails) | 1.3898 | 3.9349 | 1.2964 | 0.9280 | 1.6121 |
| | Clams/mussels | Bivalvia (non-Crassostrea) | 0.1699 | 1.0782 | 2.2922 | 2.7349 | 1.1626 |
| | Slipper shells | Gastropoda (slipper shells) | 0.0004 | 0.0008 | 0.0079 | | |
| **Crustaceans** | Hermit crabs | Paguridae | 0.0742 | 0.0684 | 0.1134 | 0.0783 | 0.0689 |
| | Amphipods | Amphipoda | 0.0374 | 0.0816 | 0.1071 | 0.1086 | 0.0336 |
| | Isopods | Isopoda | 0.0138 | 0.0505 | 0.0166 | 0.0129 | 0.0084 |
| | Mud crabs | Pleocyemata (Xanthidae) | | 0.2539 | 0.0986 | 0.0691 | 0.3045 |
| | Shrimp | Pleocyemata (Caridea) | 0.0032 | 0.1852 | 0.0574 | 0.0527 | 0.0516 |
| | Burrowing shrimp | Pleocyemata (Axiidea) | 0.0016 | 0.0388 | 0.0310 | 0.0300 | 0.0049 |
| | Pea crabs | Brachyura (Pinnotheridae) | 0.0013 | 0.0012 | 0.0298 | 0.0326 | 0.0437 |
| | Other shrimp | Pleocyemata | 0.0013 | | 0.0284 | | |
| | Mantis shrimp | Stomatopoda | 0.0009 | | | | 0.1696 |
| | Cumaceans | Malacostraca (Cumacea) | | 0.0001 | 0.0001 | 0.0006 | 0.0001 |
| | Lady crabs | Pleocyemata (Ovalipes) | | | | | 0.0670 |
| | Barnacles | Balanidae | | | | | 0.0019 |
| | Fiddler crabs | Pleocyemata (Ocypodidae) | | | | | 0.5853 |
| | Mysids | Malacostraca (Mysida) | | | | | 0.0003 |
| **Other Animals** | Bony Fish | Osteichthyes | 0.0157 | 2.2024 | 1.1279 | 0.0550 | |
| | Sea cucumbers | Echinodermata (sea cucumber) | | 1.5677 | 2.7939 | | |
| | Hemichordates | Hemichordata | 0.0025 | 0.0281 | | | |
| | Fly larvae | Diptera | | <0.0001 | 0.0021 | 0.0035 | 0.0013 |
| | Anemones | Cnidaria (Actiniaria) | 0.0059 | <0.0001 | 0.0066 | 0.0041 | |

**Table 14-5**. Summary of the total biomass (ash-free dry wt., g/m$^2$) of broad taxa collected in 27 soft-sediment samples in three study areas near Wachapreague, VA during summer 2018-2023. A blank cell indicates the absence of that taxon.

| Taxonomic Grouping | Geographic Area | 2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|---|
| ***All Taxa Combined*** | *All 3 Areas* | *8.6535* | *14.5939* | *13.4859* | *8.9918* | *6.6323* |
| **All Taxa Combined** | Bradford Bay | 13.5688 | 16.9047 | 18.6619 | 5.8322 | 5.4275 |
| | Burton's Bay | 5.1649 | 19.5651 | 10.2144 | 8.6282 | 8.7985 |
| | Wach. Inlet | 6.7526 | 6.9978 | 11.5813 | 12.5149 | 5.6709 |
| **Macroalgae** (Seaweeds) | Bradford Bay | 7.1701 | 4.9842 | 3.7909 | 0.8749 | |
| | Burton's Bay | 0.3895 | 3.0805 | | 5.9184 | 0.7192 |
| | Wach. Inlet | 3.3630 | 0.4243 | 1.4957 | 2.6321 | 0.4430 |
| **Vascular Plants** (Eelgrass etc.) | Bradford Bay | | | | | |
| | Burton's Bay | | | | | |
| | Wach. Inlet | | | 4.4357 | | 1.6610 |
| **Worms** | Bradford Bay | 5.5144 | 3.2254 | 2.9748 | 2.7210 | 2.9411 |
| | Burton's Bay | 3.5214 | 2.1201 | 2.7211 | 1.6324 | 1.3917 |
| | Wach. Inlet | 0.3966 | 0.8378 | 0.8343 | 0.7935 | 0.3934 |
| **Mollusks** (Snails, clams, etc.) | Bradford Bay | 0.7926 | 1.2694 | 1.4257 | 1.9691 | 1.1774 |
| | Burton's Bay | 1.2137 | 9.2109 | 5.1736 | 0.8470 | 4.7687 |
| | Wach. Inlet | 2.6266 | 5.2821 | 4.3635 | 8.1728 | 2.3781 |
| **Crustaceans** (Crabs, shrimp, amphipods etc.) | Bradford Bay | 0.0617 | 1.3271 | 0.6356 | 0.1801 | 1.3090 |
| | Burton's Bay | 0.0305 | 0.2374 | 0.3629 | 0.2074 | 1.9149 |
| | Wach. Inlet | 0.2949 | 0.3863 | 0.4521 | 0.8387 | 0.7953 |
| **Other Animals** (Fish, echinoderms, anenomes etc.) | Bradford Bay | 0.0301 | 6.0987 | 9.8350 | 0.0872 | |
| | Burton's Bay | 0.0097 | 4.9161 | 1.9568 | 0.0230 | 0.0040 |
| | Wach. Inlet | 0.0716 | 0.0672 | | 0.0778 | |

**Table 14-6**. Summary of the total individual density (# m$^{-2}$) of genera collected in 27 soft-sediment samples pooled for three study areas near Wachapreague, VA during summer 2018-2023. A "+" indicates presence of a taxa, typically those where counting individuals is impractical, and a blank cell indicates the absence of that taxon. To be included in this table, a taxon must be present in more than one previous year or in the current sampling year.

| | **#/m2** | | | | |
|---|---|---|---|---|---|
| **Taxon (~Genus)** | **2018** | **2019** | **2020** | **2021** | **2023** |
| ***All Taxa*** | *468* | *630* | *975* | *1,364* | *536* |
| **Amphipoda** | 67.5 | 136.1 | 301.2 | 604.2 | 176.6 |
| *Ampelisca* | 25.8 | 4.8 | 136.1 | 489.7 | 28.2 |
| *Ampithoe* | 7.6 | 1.1 | 18.5 | 12.8 | 10.1 |
| *Caprella* | | | 11.5 | | 1.8 |
| *Corophium* | 1.8 | 4.3 | 19.8 | 41.0 | 69.6 |
| *Gammarus* | 11.7 | 110.4 | 65.6 | 5.3 | 11.5 |
| *Haustorid* | 17.6 | 3.8 | 9.2 | | 3.5 |
| *Idunella* | | 1.6 | 14.1 | 54.6 | 7.5 |
| *Melita* | 2.9 | 3.2 | 6.2 | 0.4 | |
| *Paracaprella* | | | 0.9 | | 0.9 |
| *Microdeutopus* | | | 7.9 | | 2.6 |
| *Paraphoxus* | | | | 0.4 | 9.2 |
| *Ericthonius* | | | 5.3 | | 31.7 |
| **Balanidae** | | | | | 0.9 |
| Amphibalanus | | | | | 0.9 |
| **Bivalvia (non-Crassostrea)** | 29.3 | 98.1 | 285.4 | 495.0 | 77.5 |
| *Ensis* | 0.6 | 38.6 | 207.4 | 435.5 | 43.6 |
| *Gemma* | 4.7 | | | 0.4 | 0.4 |
| *Macoploma* | 12.9 | 24.1 | 39.2 | 34.4 | 22.9 |
| *Mercenaria* | 1.8 | | 0.4 | 0.9 | 1.3 |
| *Mulinia* | 1.8 | 22.5 | 0.9 | 4.4 | 1.8 |
| *Mya* | 4.7 | 1.1 | | 1.8 | |
| *Mytilus* | | | 21.1 | 0.9 | 2.6 |
| *Petricolaria* | | | 7.9 | | 0.9 |
| *Tagelus* | 1.2 | 4.8 | 3.1 | 3.1 | 3.5 |
| *Macoma* | 1.8 | 4.8 | 5.3 | 13.7 | 0.4 |
| **Brachyura (Pinnotheridae)** | 1.8 | 1.1 | 10.6 | 18.9 | 4.4 |
| *Pinnixulala* | 1.8 | | 10.6 | 18.5 | 1.3 |
| *Rathbunixa* | | 1.1 | | 0.4 | 1.3 |
| *Tubicolixa* | | | | | 1.8 |

*Table continued on next page*

**Table 14-6** (continued)

| Taxon (~Genus) | #/m2<br>2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|
| **Cnidaria (Actiniaria)** | 2.3 | 0.5 | 1.8 | 0.9 | |
| *Diadumene* | 2.3 | | 1.3 | | |
| *Edwardsiella* | | 0.5 | | 0.9 | |
| **Diptera** | | 0.5 | 0.9 | 2.6 | 0.9 |
| Diptera | | 0.5 | 0.9 | 2.6 | 0.9 |
| **Echinodermata** | | 1.1 | 0.9 | | |
| *Sclerodactyla* | | 1.1 | 0.9 | | |
| **Gastropoda (slipper shells)** | 0.6 | 0.5 | 0.9 | | |
| *Crepidula* | 0.6 | 0.5 | 0.9 | | |
| **Gastropoda (snails)** | 66.9 | 107.2 | 89.8 | 42.3 | 62.1 |
| *Acteocina* | 2.3 | 2.7 | 12.3 | 8.4 | 8.8 |
| *Astyris* | 0.6 | 3.2 | 14.5 | 6.2 | 6.6 |
| *Bittiolum* | | | 2.2 | 1.3 | 5.3 |
| *Costoanachis* | | | 0.4 | 1.3 | 0.9 |
| *Haminella* | | 33.8 | 26.4 | 5.7 | 4.0 |
| *Nucella* | | 0.5 | | 3.1 | |
| *Phrontis* | 1.8 | | 0.4 | | 0.9 |
| *Seila* | 0.6 | 0.5 | 6.6 | | 2.6 |
| *Tritia* | 61.6 | 65.9 | 26.0 | 14.5 | 31.7 |
| *Pyrgocythara* | | | | | 1.3 |
| **Hemichordata** | 1.2 | 1.1 | | | |
| *Saccoglossus* | 1.2 | 1.1 | | | |
| **Isopoda** | 5.3 | 17.7 | 9.2 | 10.1 | 4.0 |
| *Cyathura* | 1.8 | 15.0 | 6.6 | 4.0 | 2.6 |
| *Edotia* | 0.6 | 2.7 | 2.6 | 6.2 | 1.3 |
| **Macroalgae** | + | + | + | + | + |
| *Ceramium* | | | + | | + |
| *Gracilaria* | + | + | + | + | |
| *Ulva* | + | + | + | + | + |
| *Ectocarpus* | | | | | + |
| **Malacostraca (Cumacea)** | | 0.5 | 1.8 | 1.3 | 1.8 |
| . | | 0.5 | 1.8 | 1.3 | 1.8 |
| **Malacostraca (Mysida)** | | | | | 0.4 |
| . | | | | | 0.4 |
| **Nemertea** | 1.2 | 0.5 | 1.3 | | 0.4 |
| *Micrura* | 1.2 | 0.5 | 1.3 | | 0.4 |

*Table continued on next page*

**Table 14-6** (continued)

| Taxon (~Genus) | #/m2<br>2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|
| **Osteichthyes** | 1.8 | 1.1 | 0.4 | 0.9 | |
| *Conger* | | 0.5 | 0.4 | | |
| **Paguridae** | 2.3 | 4.3 | 5.7 | 4.0 | 6.2 |
| *Pagurus* | 2.3 | 4.3 | 5.7 | 4.0 | 6.2 |
| **Pleocyemata (Axiidea)** | 0.6 | 5.4 | 11.9 | 7.0 | 3.1 |
| *Biffarius* | 0.6 | 4.3 | 11.5 | 5.3 | 3.1 |
| *Upogebia* | | 1.1 | 0.4 | 0.4 | |
| **Pleocyemata (Caridea)** | 1.8 | 9.1 | 8.4 | 3.1 | 4.4 |
| *Alpheus* | | 2.1 | 1.3 | 0.4 | 1.3 |
| *Crangon* | | 0.5 | 1.3 | | 0.4 |
| *Ogyrides* | 0.6 | 6.4 | 5.7 | 2.2 | 2.6 |
| **Pleocyemata (Ocypodidae)** | | | | | 3.5 |
| *Minuca* | | | | | 3.5 |
| **Pleocyemata (Ovalipes)** | | | | | 0.4 |
| *Ovalipes* | | | | | 0.4 |
| **Pleocyemata (Xanthidae)** | | 9.1 | 11.5 | 1.3 | 6.6 |
| *Dyspanopeus* | | 0.5 | | | 0.9 |
| *Eurypanopeus* | | 5.9 | 8.8 | | 1.3 |
| *Panopeus* | | 2.7 | 2.6 | 1.3 | 4.4 |
| **Polychaeta** | 282.8 | 229.9 | 230.8 | 172.2 | 182.8 |
| *Alitta* | 221.2 | 143.6 | 77.1 | 63.0 | 70.9 |
| *Arabella* | 1.2 | 2.7 | 8.4 | 3.5 | 2.6 |
| *Capitellidae* | | | | | 0.9 |
| *Chaetopterus* | | | | | 0.9 |
| *Clymenella* | 14.1 | 9.1 | 22.9 | 14.5 | 60.8 |
| *Diopatra* | 2.9 | 1.6 | 2.2 | | 1.3 |
| *Drilonereis* | 28.7 | 42.3 | 44.5 | 24.7 | 9.7 |
| *Glycera* | 7.0 | 10.2 | 15.9 | 18.1 | 11.5 |
| *Lepidonotus* | 0.6 | | 0.4 | | 1.3 |
| *Maldane* | 1.2 | 0.5 | | 0.9 | |
| *Marphysa* | 2.9 | 4.3 | 7.9 | 2.6 | 1.8 |
| *Melinna* | | | 0.4 | 0.9 | |
| *Nephtys* | | 3.2 | 0.4 | 0.4 | |
| *Orbinidae* | | 1.1 | 23.3 | 33.9 | 6.2 |

*Table continued on next page*

**Table 14-6** (continued)

| Taxon (~Genus) | #/m2<br>2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|
| *Owenia* | | | 11.0 | 1.3 | 12.3 |
| *Pectinaria* | 0.6 | 1.6 | 1.8 | 0.4 | 0.4 |
| *Phyllodoce* | | 1.1 | 1.8 | 1.8 | 1.3 |
| *Piromis* | | 1.1 | 1.3 | 0.4 | |
| *Spiochaetopterus* | 1.2 | 1.1 | 5.3 | 3.5 | 0.9 |
| **Stomatopoda** | 0.6 | | | | 0.4 |
| *Squilla* | 0.6 | | | | 0.4 |
| **Vascular plant** | | | + | | + |
| *Zostera* | | | + | | + |

**Table 14-7**. Summary of several community metrics (based on density of individual organisms, # m$^{-2}$) of faunal taxa (basically at the level of genus) collected in 27 soft-sediment samples overall and in three study areas near Wachapreague, VA during summer 2018-2023.

| Community Metric | Geographic Area | 2018 | 2019 | 2020 | 2021 | 2023 |
|---|---|---|---|---|---|---|
| **Abundance (# m$^{-2}$)** | Bradford Bay | 642 | 680 | 835 | 569 | 547 |
| | Burton's Bay | 401 | 867 | 805 | 499 | 394 |
| | Wach. Inlet | 353 | 334 | 1,288 | 3,024 | 669 |
| | *Overall* | *468* | *630* | *976* | *1,364* | *536* |
| **Taxa Richness** | Bradford Bay | 29 | 41 | 52 | 35 | 43 |
| | Burton's Bay | 30 | 40 | 50 | 37 | 39 |
| | Wach. Inlet | 35 | 37 | 42 | 45 | 43 |
| | *Overall* | *52* | *67* | *80* | *64* | *70* |
| **Shannon Diversity Index (H')** | Bradford Bay | 1.47 | 2.51 | 2.84 | 2.77 | 2.66 |
| | Burton's Bay | 1.85 | 2.37 | 3.27 | 2.68 | 2.87 |
| | Wach. Inlet | 2.48 | 2.63 | 2.28 | 1.45 | 2.48 |
| | *Overall* | *2.21* | *2.82* | *3.12* | *2.09* | *3.16* |

**Figure 14-1** Smith-McIntyre grab used to collect benthic fauna in soft-sediment.

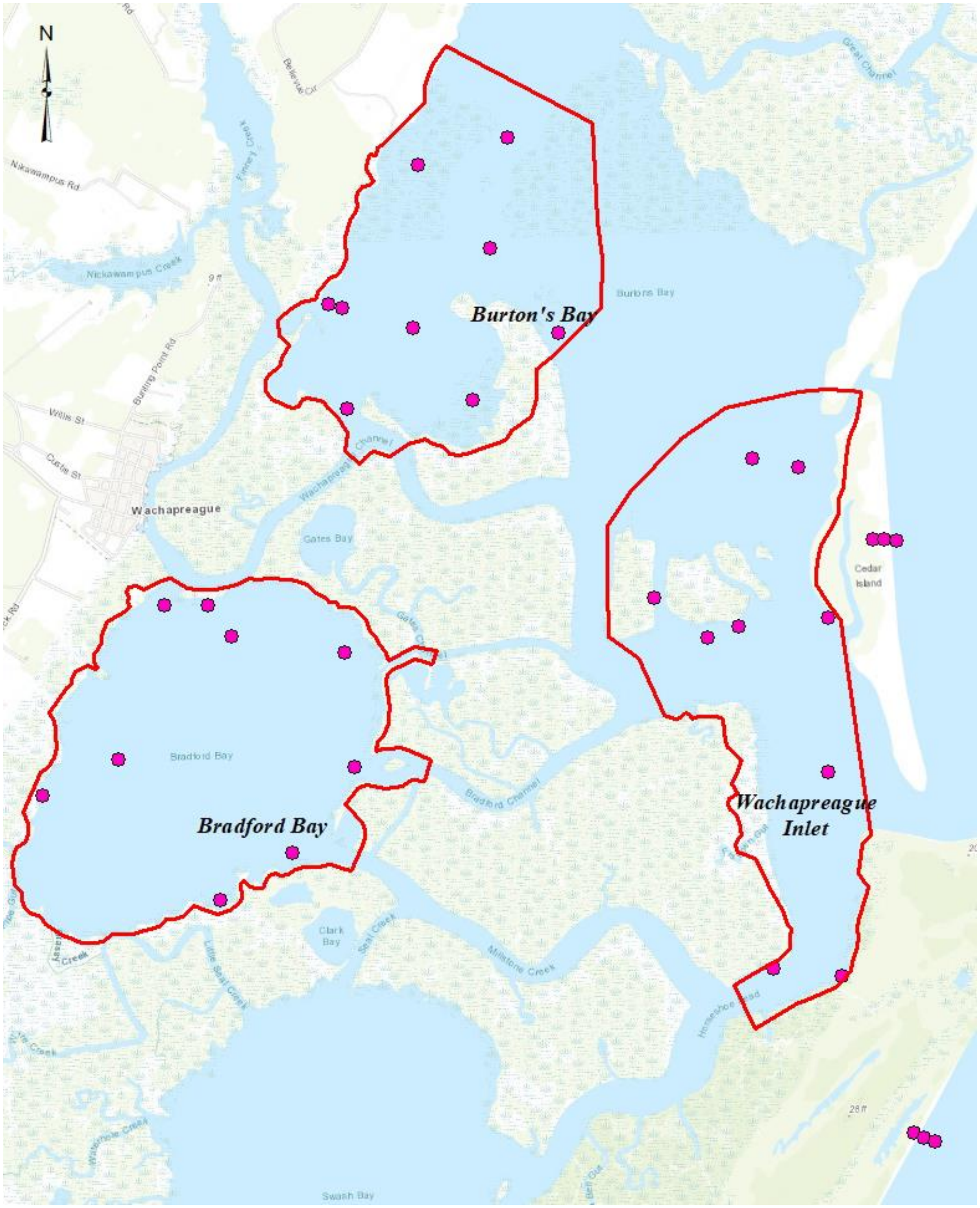

**Figure 14-2** Locations of 27 grab sample sites where organisms were collected near Wachapreague, VA in 2018-2023 (red polygons denote the ESL-EMP study areas). The six sites outside the red polygons are ocean sites off Cedar and Parramore islands that were sampled in 2022 and 2023 but not reported on in this document.

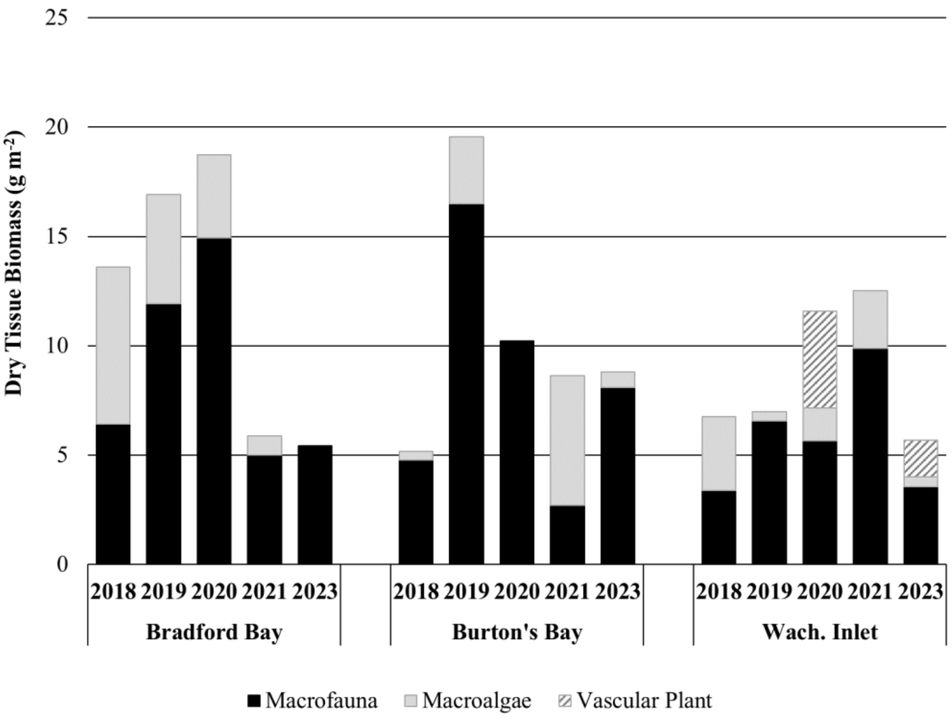

**Figure 14-3** Dry tissue biomass (g m$^{-2}$) of macroalgae vs. macrofauna vs. vascular plants in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2023.

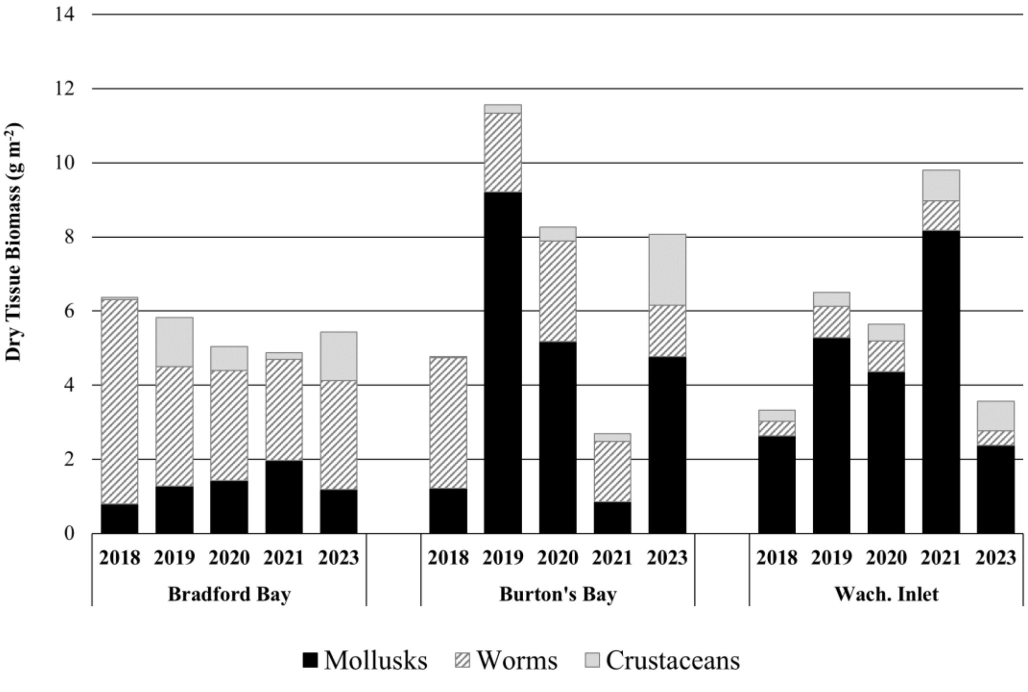

**Figure 14-4** Dry tissue biomass (g m$^{-2}$) of three ecologically important macrofaunal broad taxa collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2023.

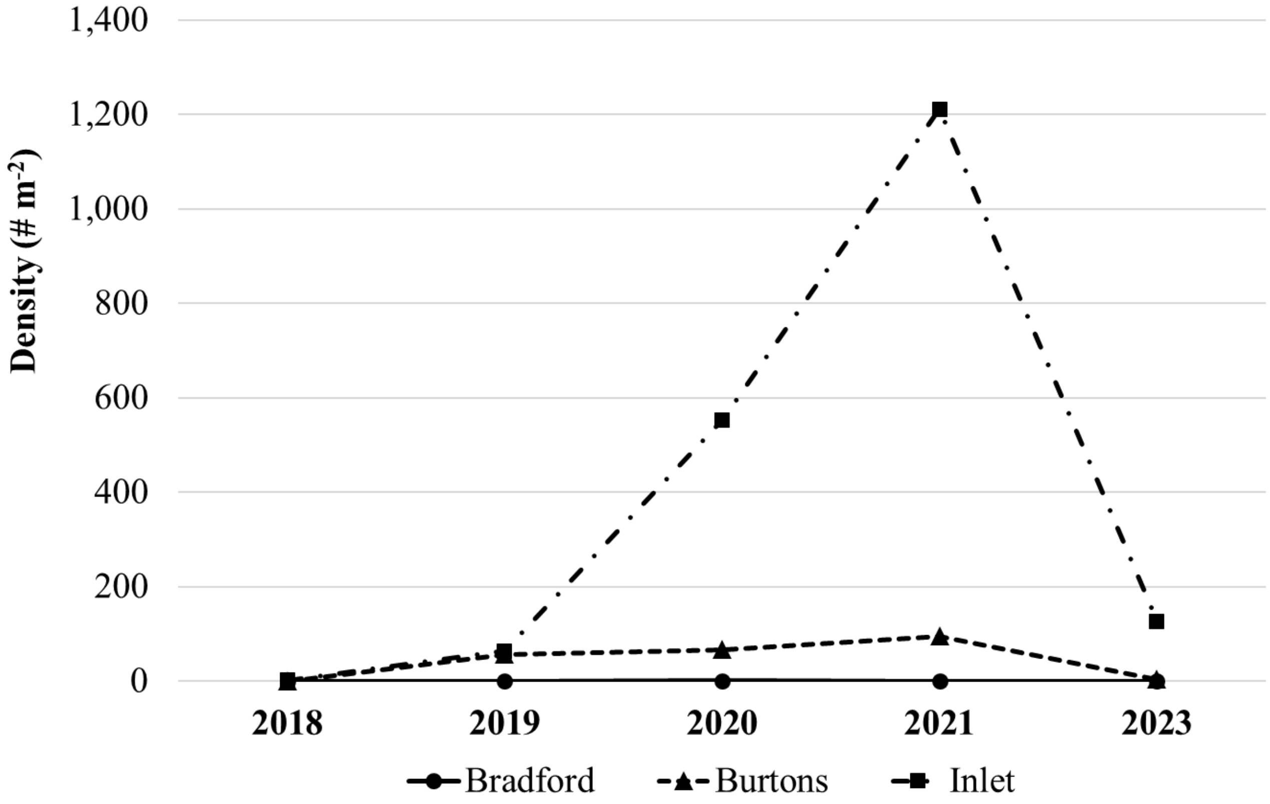

**Figure 14-5** Density (# m$^{-2}$) of *Ensis leei* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2018-2023.

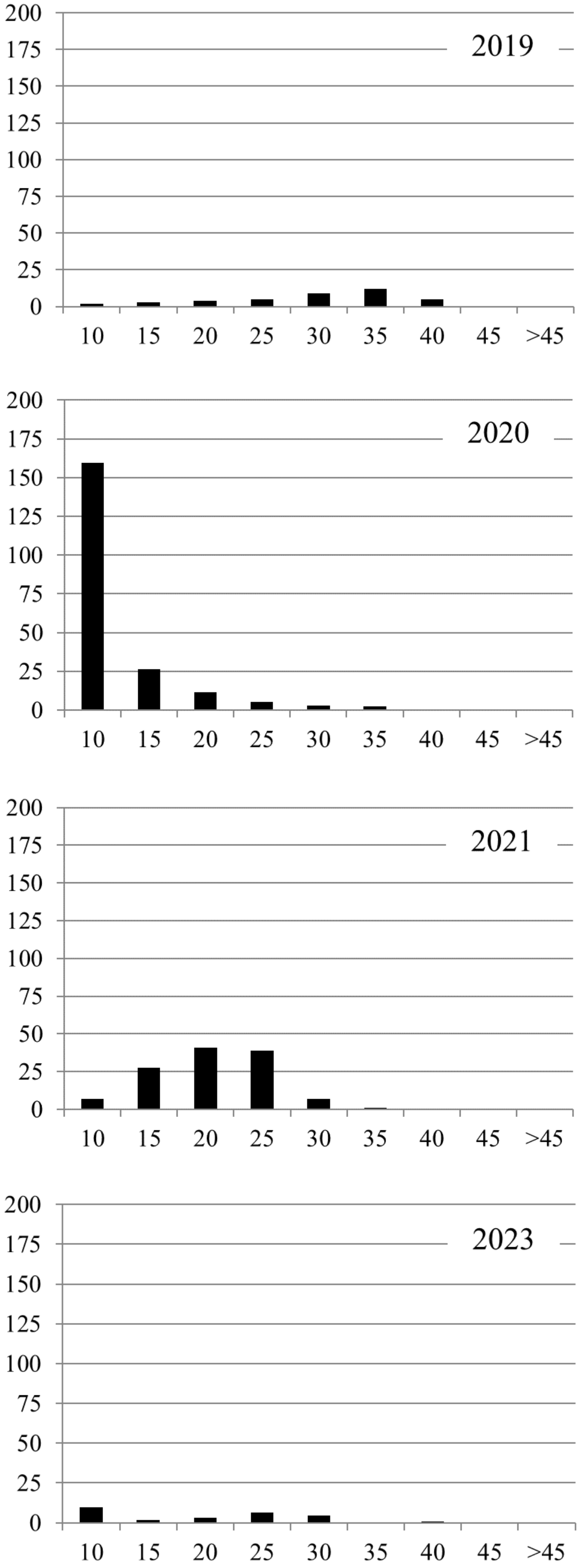

**Figure 14-6** Size frequency distribution (shell width, mm) of *Ensis leei* collected in soft-sediment samples in 3 regions near Wachapreague, VA during summer 2019-2023.

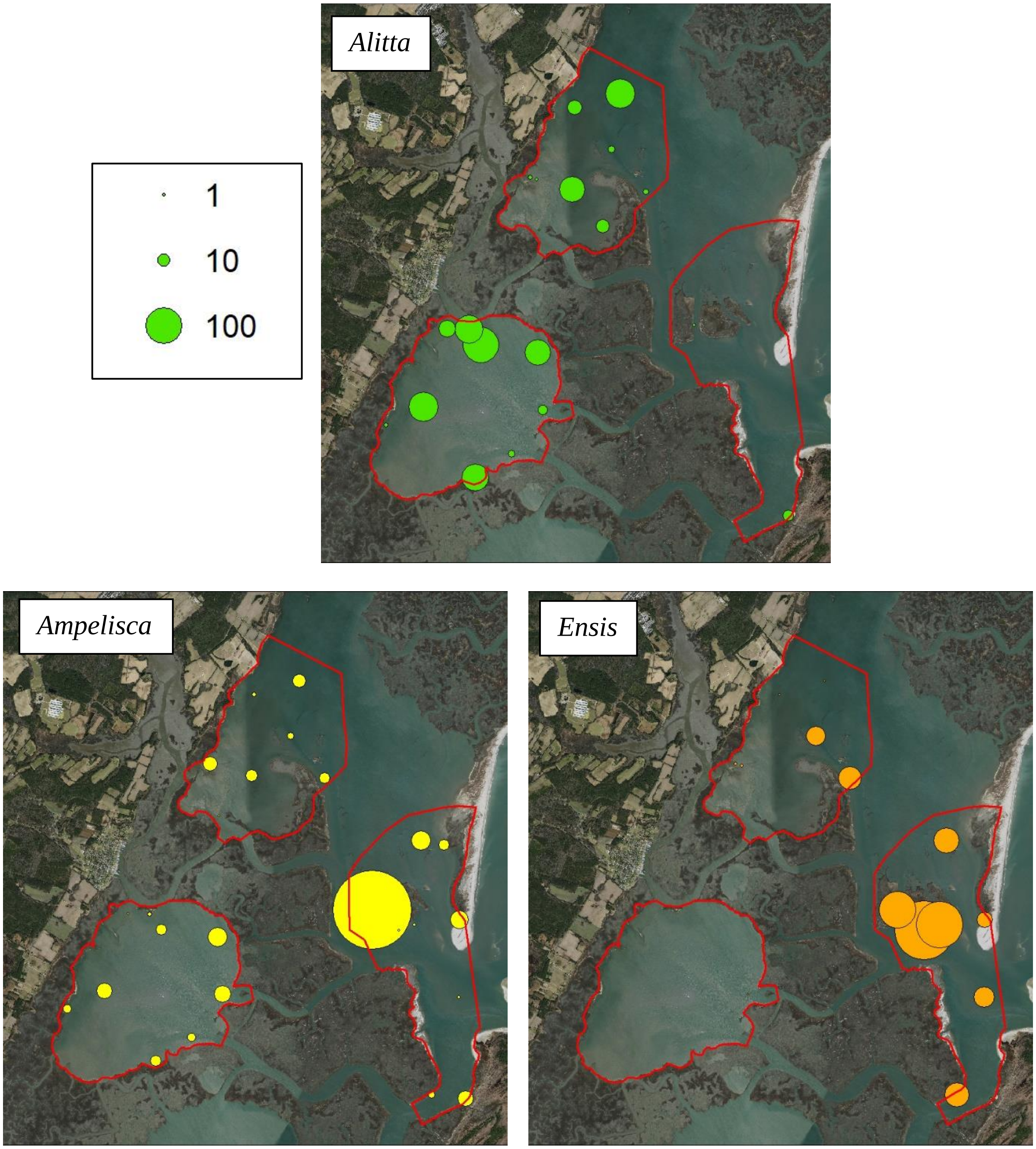

**Figure 14-7**. Total number of individuals collected over 5 years from 2018-2021 and 2023 at 27 grabs sample sites of three genera (above, left to right): polychaete *Alitta* (green; legend to left in green), amphipod *Ampelisca* (yellow) and bivalve *Ensis* (orange). The size of circles equates to the quantity of organisms collected (legend for *Ampelisca* and *Ensis* to the left in gray). Red polygons denote the ESL-EMP study areas.

# Chapter 15. Soft Seabed Nekton Community

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**7-year sampling plan:**

| *2018* | *2019* | *2020* | *2021* | *2022* | *2023* | *2024* |
|---|---|---|---|---|---|---|
| | | | Complete | Complete | Complete | Planned |

## Introduction

Areas such as coastal bays along the Delmarva Peninsula are known to be important nursery and forage habitats for an array of nekton (highly mobile organisms) that have ecological and commercial importance. Additionally, these oceanic coastal areas are some of the most dynamic habitats in the world. More specifically, rapid changes have been and are forecast to continue to significantly impact the mid-Atlantic region in coming decades (see Colgan et al. 2018).

Potential impacts of coastal change are well documented for nekton (see Colombano et al. 2021 and Kimball et al. 2020). We have been monitoring the epi-benthic communities in the vicinity of Wachapreague Inlet since 2018 (Ross and Snyder 2020). Adding data on the nekton community starting 2021 will provide a more holistic documentation of the status and trends of the marine ecosystem in the vicinity of the Eastern Shore Laboratory.

## Study Area & Methods

Six sites were selected within each of the three EMP geographical areas to trawl for motile invertebrates and fish (18 sites total; Fig. 15-1). Some of these were sites where we also collect soft-sediment benthic grab samples (see Chapter 14). All sites were sampled three times during the year in late-spring, summer, and late-summer. These trawls were completed during June 5-7, July 24-26, and September 5-7, 2023, respectively.

We used a 4.88 m (16’) nylon otter trawl with a 3.8 cm (1.5”) mesh body, 3.2 cm (1.25”) mesh bag and 5 mm (3/16”) Delta knotless cod liner. This trawl was paired with 76 cm x 38 cm trawl boards and 30.5 m tow lines.

At each location, trawling transects were ~440 m approximately centered on the grab sample sites. Trawls were oriented into the current as much as possible based on the seabed topography with a ground speed of 2.5-3.5 kts. Based on the trawl’s 4.88 m head rope, we used a 0.55 wing spread ratio combined with the actual distance trawled to calculate the Area Swept for each site (targeted ~ 1,180 m$^2$). Within each of the three geographic areas, three of the trawl sites were located in shallow subtidal areas ($\leq$ 1.5 m MLLW) and three were in channel/edge areas (>1.5 m MLLW). Shallow subtidal sites were sampled within two hrs of high tide and channel edge areas were sampled within three hrs of low tide. Organisms were immediately identified, measured and returned to the water.

Additionally, in each of the three regions we selected one intertidal/shallow subtidal site with a sandy shore for two paired beach seines (three sites and six total seines; Fig. 15-1). All sites were sampled seasonally during the year in late-spring, summer, and late-summer. These seines were completed during June 7-9, July 25-26, and September 6-7, 2023, respectively.

We used a 15.2 m seine that was 1.5 m deep and constructed of 6.4 mm (1/4”) Delta knotless mesh material that included a “box” built into the middle (Fig. 15-2). Beginning in approximately 1 m water depth, the beach seine was pulled directly towards shore until the net was completely on land and out of the water. Start and end points for seining were marked with a sub-meter accuracy GPS (Trimble) allowing the exact area sampled to be calculated. Organisms were immediately put in buckets of water, identified, measured and returned to the water.

## 2023 Results & Comparison to Previous Years

### Trawl

The area swept within region x sub-habitat x season ranged from 2,969 to 3,870 $m^2$ for individual trawls (Table 15-1). Overall, 4,399 (685 $hectare^{-1}$) organisms, representing 46 species, were caught in 54 tows. Bony fish (*Osteichthyes*) were dominant (Table 15-2). Overall, more organisms were caught in late-spring and summer vs. late-summer, however taxa-specific seasonality varied (Table 15-2). Geographic differences were also seen in trawl data, although patterns varied between taxa and seasons (Table 15-3). Mean density of taxa groups are reported in Table 15-4 for 2021-2023 by season. The high numbers of organisms (mainly teleosts) collected in 2022 appears to be an outlier relative to 2021 and 2023 at this point. As expected, taxa group by year and by season patterns appear to be complex and variable (Table 15-4).

Detailed yearly sample densities for individual species are reported in Table 15-5. As expected, schooling prey fish species such as bay anchovies (*Anchoa mitchelli*) and juvenile spot (*Leiostomus xanthrus*) were dominant in all years. Of note, less juvenile black seabass (*Centroprista striata*) were caught in 2023 samples than we anticipated based on previous years. Additionally, a pulse of weakfish (*Cynoscion regalis*) was seen in 2023, but almost entirely consisted to very small juveniles. There were some interesting patterns in year x season densities for select finfish and crustacean species (Tables 15-6 and 15-7). For now, we present these as simple heat map tables. As more data is collected, teasing out these patterns statistically will be a priority. Taxa richness and diversity (i.e., Shannon Diversity Index, H’) were variable between years and geographic study areas (Table 15-8).

Sizes of select species are reported in Table 15-9 for trawl and seine samples pooled together. The average size for most fish species increased throughout the year (late-spring<summer<late-summer) whereas blue crabs show a different pattern.

Beach Seine

The area swept within region x sub-habitat x season ranged from 349 to 525 $m^2$ for seines (Table 15-1). Overall, 2,054 (4,933 $hectare^{-1}$) organisms, representing 41 species, were caught in 18 seines. Bony fish (*Osteichthyes*) were dominant (Table 15-10). More fish were caught in late-spring and summer vs. late-summer whereas more blue crabs (*Callinectes* spp.) were caught in summer vs. earlier and later in the year (Table 15-10). Geographic differences were also seen in seine data, although patterns varied between taxa and seasons (Table 15-11). Mean density of taxa groups are reported in Table 15-12 for 2021-2023 by season. As noted above for trawls, the high numbers of organisms (mainly teleosts) collected in 2022 appears to be an outlier relative to 2021 and 2023 at this point. This pattern was essentially driven by a large catch of menhaden (*Brevoortia tyrranus*) in one 2022 late-spring seine in Burton's Bay (Table 15-13). For seines, as expected, taxa group by year and by season patterns appear to be complex and variable (Table 15-12).

Detailed seasonal sample densities for individual species are reported in Table 15-13. As expected, schooling prey species such as Atlantic silversides (*Menidia menidia*) and juvenile spot (*Leiostomus xanthrus*) were dominant. The number of pinfish (*Lagodon rhomboides*) was noticably less in 2023 seine samples (Table 15-3). There were some interesting patterns in year x season densities for select finfish and crustacean species (Tables 15-14 and 15-15). For now, we present these as simple heat map tables. As more data is collected, teasing out these patterns statistically will be a priority. Taxa richness and diversity (i.e. Shannon Diversity Index, H') were variable between years and geographic study areas (Table 15-16). As mentioned above, sizes of select species are reported in Table 15-9 for trawl and seine samples pooled together.

## 2023 Acknowledgements

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**Table 15-1**. Nekton community sampling total *area swept* ($m^2$) for each individual season for late-spring, summer, and late-summer within three regions near Wachapreague, VA during 2023.

| Region | Sub-habitat | Gear | 2023 | | |
|---|---|---|---|---|---|
| | | | **Late-Spring** | **Summer** | **Late-Summer** |
| Bradford Bay | Shallow Subtidal | Trawl Tows (n=3) | 3,570 | 3,739 | 3,538 |
| | | Beach Seines* (n=2) | 413 | 496 | 454 |
| | Deep/Channel Edge | Trawl Tows (n=3) | 3,211 | 3,602 | 3,623 |
| Burton's Bay | Shallow Subtidal | Trawl Tows (n=3) | 3,570 | 3,809 | 3,470 |
| | | Beach Seines (n=2) | 515 | 355 | 349 |
| | Deep/Channel Edge | Trawl Tows (n=3) | 2,969 | 3,631 | 3,637 |
| Wach. Inlet | Shallow Subtidal | Trawl Tows (n=3) | 3,629 | 3,731 | 3,430 |
| | | Beach Seines (n=2) | 525 | 483 | 451 |
| | Deep/Channel Edge | Trawl Tows (n=3) | 3,574 | 3,870 | 3,843 |

* Seines actually cover part of the shallow subtidal and intertidal zones adjacent to sample sites

**Table 15-2**. Summary of the total abundace (#) and density (mean # hectare$^{-1}$) of broad taxa collected in trawls (n=18 each period) near Wachapreague, VA during three sample periods (late-spring, summer and late-summer) in 2023. A blank cell indicates the absence of that taxon.

| **Sample Type** | | **Common Name** | **Representative Taxonomic Grouping** | **2023 Total #** | | | **2023 Mean # hectare$^{-1}$** | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Late-Spring** | **Summer** | **Late-Summer** | **Late-Spring** | **Summer** | **Late-Summer** |
| ***TRAWLS*** | ***All Taxa*** | | | *1,519* | *2,322* | *558* | *732.3* | *1,063.7* | *258.6* |
| | **Fish** | Teleosts | Osteichthyes | 1,424 | 1,855 | 410 | 682.2 | 850.6 | 190.4 |
| | | Elasmobranchs | Chondrichthyes (Elasmobranchii) | 3 | 11 | | 1.6 | 5.0 | |
| | **Crustaceans** | Blue Crabs | Pleocyemata (Callinectes) | 19 | 49 | 25 | 9.4 | 22.9 | 11.5 |
| | | Lady Crabs | Pleocyemata (Ovalipes) | 6 | 20 | 4 | 2.8 | 8.9 | 1.9 |
| | | Spider Crabs | Brachyura (Epialtidae) | 7 | 2 | 1 | 3.4 | 1.0 | 0.5 |
| | | Penaid Shrimps | Dendrobranchiata (Penaeidae) | 1 | 2 | 52 | 0.6 | 1.0 | 23.8 |
| | | Non-penaid Shrimps | Pleocyemata (Caridea) | 40 | 1 | 2 | 22.6 | 0.4 | 0.9 |
| | **Mollusks** | Squids | Cephalopoda | 11 | 367 | 58 | 5.7 | 167.4 | 27.0 |
| | | Snails | Gastropoda (snails) | | | 1 | | | 0.5 |
| | **Other Animals** | Mantis Shrimps | Stomatopoda | 8 | 12 | 5 | 4.1 | 5.3 | 2.3 |
| | | Terrapins | Emydidae | | 1 | | | 0.5 | |
| | | Urchins | Echinodermata (sea urchin) | | 2 | | | 0.8 | |

**Table 15-3**. Summary of the density (mean # hectare$^{-1}$) of select broad taxa collected in trawls (n=6 for each geographic area and season) near Wachapreague, VA during late-spring, summer and late-summer 2023. A blank cell indicates the absence of that taxon.

| Sample Type | Representative Taxonomic Grouping | Geographic Area | 2023 Mean # hectare$^{-1}$ | | |
|---|---|---|---|---|---|
| | | | Late-Spring | Summer | Late-Summer |
| *TRAWLS* | **Osteichthyes**<br>Teleosts | Bradford Bay | 682.9 | 1,434.7 | 339.0 |
| | | Burton's Bay | 964.0 | 982.1 | 113.5 |
| | | Wach. Inlet | 399.7 | 134.8 | 118.6 |
| | **Chondrichthyes (Elasmobranchii)**<br>Elasmobranchs | Bradford Bay | | | |
| | | Burton's Bay | 2.1 | 5.5 | |
| | | Wach. Inlet | 1.4 | | |
| | **Pleocyemata (Callinectes)**<br>Blue Crabs | Bradford Bay | 14.0 | 22.3 | 24.8 |
| | | Burton's Bay | 7.4 | 46.5 | 2.9 |
| | | Wach. Inlet | 6.7 | | 6.8 |
| | **Dendrobranchiata (Penaeidae)**<br>Penaid Shrimps | Bradford Bay | 1.7 | | 65.8 |
| | | Burton's Bay | | 2.9 | 5.5 |
| | | Wach. Inlet | | | |
| | **Cephalopoda**<br>Squids | Bradford Bay | | | |
| | | Burton's Bay | 11.3 | 213.0 | 14.1 |
| | | Wach. Inlet | 1.3 | 94.4 | 34.3 |

**Table 15-4**. Summary of the overall mean density (# hectare$^{-1}$) of select common broad taxa collected in trawls (n=18 each season) for three sample periods (late-spring, summer and late-summer) near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---").

| Sample Type | Broad Taxa | Common Name | Representative Taxonomic Grouping | Season | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|
| *TRAWLS* | Fish | Teleosts | Osteichthyes | Late-Spring | 640.8 | 3,043.7 | 682.2 |
| | | | | Summer | --- | --- | 850.6 |
| | | | | Late-Summer | 504.1 | 2,028.7 | 190.4 |
| | | Elasmobranchs | Chondrichthyes (Elasmobranchii) | Late-Spring | 6.1 | 7.3 | 1.6 |
| | | | | Summer | --- | --- | 5.0 |
| | | | | Late-Summer | 0.5 | 1.3 | 0.0 |
| | Crustaceans | Blue Crabs | Pleocyemata (Callinectes) | Late-Spring | 21.4 | 84.0 | 9.4 |
| | | | | Summer | --- | --- | 22.9 |
| | | | | Late-Summer | 18.5 | 48.4 | 11.5 |
| | | Lady Crabs | Pleocyemata (Ovalipes) | Late-Spring | 181.3 | 5.2 | 2.8 |
| | | | | Summer | --- | --- | 8.9 |
| | | | | Late-Summer | 0.5 | 2.9 | 1.9 |
| | | Spider Crabs | Brachyura (Epialtidae) | Late-Spring | 1.4 | 1.4 | 3.4 |
| | | | | Summer | --- | --- | 1.0 |
| | | | | Late-Summer | | | 0.5 |
| | | Penaid Shrimps | Dendrobranchiata (Penaeidae) | Late-Spring | 8.0 | 4.2 | 0.6 |
| | | | | Summer | --- | --- | 1.0 |
| | | | | Late-Summer | 40.2 | 13.1 | 23.8 |
| | | Non-penaid Shrimps | Pleocyemata (Caridea) | Late-Spring | 6.1 | 19.2 | 22.6 |
| | | | | Summer | --- | --- | 0.4 |
| | | | | Late-Summer | 1.8 | 0.9 | 0.9 |
| | Mollusks | Squids | Cephalopoda | Late-Spring | 17.2 | 3.3 | 5.7 |
| | | | | Summer | --- | --- | 167.4 |
| | | | | Late-Summer | 20.0 | 22.9 | 27.0 |
| | Other Animals | Mantis shrimps | Stomatopoda | Late-Spring | 3.3 | 12.7 | 4.1 |
| | | | | Summer | --- | --- | 5.3 |
| | | | | Late-Summer | 2.3 | 3.7 | 2.3 |

**Table 15-5**. Summary of the density (Mean # hectare$^{-1}$) of species collected in trawls within samples pooled for geographic areas (three) and seasons (two in 2021-2022 and three in 2023) near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon.

| | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|
| **Taxon (~Species)** | **2021** | **2022** | **2023** |
| ***All Taxa*** | *739.3* | *2,652.1* | *684.9* |
| **Osteichthyes** | **572.5** | **2,536.2** | **574.4** |
| *Larval fish (unidentified)* | | 13.4 | |
| *Aluterus schoepfii* | 0.9 | 1.6 | 0.4 |
| *Anchoa mitchilli* | 304.3 | 401.2 | 73.6 |
| *Archosargus probatocephalus* | 2.5 | | |
| *Bairdiella chrysoura* | 40.5 | 32.1 | 5.4 |
| *Brevoortia tyrannus* | 0.7 | 26.6 | 0.4 |
| *Caranx hippos* | | | 1.1 |
| *Caranx sp* | 0.2 | 0.2 | |
| *Centropristis striata* | 13.9 | 17.3 | 1.7 |
| *Chaetodipterus faber* | | | 0.1 |
| *Chilomycterus schoepfii* | | 0.2 | |
| *Conger oceanicus* | | 0.2 | 0.2 |
| *Cynoscion regalis* | 2.1 | 22.4 | 98.2 |
| *Etropus crossotus* | 0.2 | | |
| *Etropus microstomus* | | 1.1 | |
| *Eucinostomus gula* | 0.2 | | |
| *Gobiosoma bosc* | 0.5 | | |
| *Hippocampus erectus* | 1.3 | 2.1 | 0.3 |
| *Hypsoblennius hentz* | | 0.5 | |
| *Lagocephalus laevigatus* | 0.5 | 1.4 | 0.2 |

*Table continued on next page*

**Table 15-5** (continued)

| Taxon (~Species) | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|
| *Lagodon rhomboides* | 12.0 | 130.5 | 7.3 |
| *Leiostomus xanthurus* | 153.2 | 1,836.4 | 365.6 |
| *Menidia menidia* | | | 0.2 |
| *Menticirrhus americanus* | 0.4 | 0.5 | 0.8 |
| *Menticirrhus saxatilis* | | 0.5 | |
| *Microgobius thalassinus* | | 0.2 | |
| *Micropogonias undulatus* | 7.0 | 9.9 | 3.6 |
| *Morone saxatilis* | 0.4 | | |
| *Mugil curema* | 0.4 | | 0.2 |
| *Ophidion marginatum* | | | 0.1 |
| *Opisthonema oglinum* | | | 0.2 |
| *Opsanus tau* | | 0.5 | |
| *Orthopristis chrysoptera* | 0.5 | 2.3 | 0.9 |
| *Paralichthys dentatus* | 2.8 | 2.1 | 3.1 |
| *Peprilus triacanthus* | 1.4 | 1.2 | |
| *Pogonias cromis* | 0.2 | | 0.2 |
| *Prionotus carolinus* | 4.7 | 3.2 | 0.8 |
| *Rachycentron canadum* | | | 0.2 |
| *Scomberomorus maculatus* | | | 4.2 |
| *Selene setapinnis* | | | 0.3 |
| *Selene sp* | 1.6 | 13.8 | |
| *Selene vomer* | | | 1.7 |
| *Sphoeroides maculatus* | 0.2 | 0.7 | |
| *Sphyraena borealis* | | 0.4 | |
| *Symphurus plagiusa* | 14.8 | 8.9 | 2.9 |
| *Syngnathus floridae* | 0.2 | 0.4 | |

*Table continued on next page*

**Table 15-5** (continued)

| Taxon (~Species) | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|
| *Syngnathus fuscus* | 0.2 | 2.8 | |
| *Synodus foetens* | 0.2 | 0.2 | |
| *Tautoga onitis* | 0.2 | | |
| *Trichiurus lepturus* | 1.2 | 0.2 | 0.3 |
| *Trinectes maculatus* | 1.2 | 0.5 | 0.2 |
| *Urophycis regia* | 1.7 | 0.7 | 0.2 |
| **Chondrichthyes (Elasmobranchii)** | **3.3** | **4.3** | **2.2** |
| *Bathytoshia centroura* | 0.2 | | |
| *Carcharhinus plumbeus* | | 0.2 | 0.2 |
| *Gymnura altavela* | 0.2 | 0.4 | |
| *Hypanus sabinus* | | 3.2 | 1.9 |
| *Hypanus say* | 0.5 | | 0.1 |
| *Mustelus canis* | 0.2 | | |
| *Raja eglanteria* | 2.1 | 0.4 | |
| **Pleocyemata (Ovalipes)** | **90.9** | **4.0** | **4.5** |
| *Ovalipes ocellatus* | 90.9 | 4.0 | 4.5 |
| **Pleocyemata (Callinectes)** | **20.0** | **66.2** | **14.6** |
| *Callinectes sapidus* | 20.0 | 61.8 | 11.9 |
| *Callinectes similis* | | 4.4 | 2.7 |
| **Pleocyemata (Cancridae)** | **1.2** | | |
| *Cancer irroratus* | 1.2 | | |
| **Brachyura (Epialtidae)** | **0.7** | **0.7** | **1.6** |
| *Libinia emarginata* | 0.7 | 0.7 | 1.6 |
| **Pleocyemata (Portunidae)** | **0.2** | **0.6** | |
| *Achelous gibbesii* | 0.2 | 0.6 | |

*Table continued on next page*

**Table 15-5** (continued)

| Taxon (~Species) | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|
| **Dendrobranchiata (Penaeidae)** | **24.1** | **8.7** | **8.4** |
| *Multiple species* | 24.1 | 8.7 | 8.4 |
| **Pleocyemata (Caridea)** | **3.9** | **10.1** | **8.0** |
| *Unidentified* | | | 0.4 |
| *Crangon septemspinosa* | 1.6 | 2.5 | 1.5 |
| *Lysmata sp* | 0.9 | 0.7 | |
| *Palaemon sp* | 1.4 | 6.8 | 6.0 |
| **Cephalopoda** | **18.6** | **13.1** | **66.7** |
| *Lolliguncula brevis* | 18.6 | 13.1 | 66.7 |
| **Gastropoda (snails)** | **0.5** | | **0.2** |
| *Busycon carica* | 0.2 | | 0.2 |
| *Busycotypus canaliculatus* | 0.2 | | |
| **Emydidae** | **0.5** | | **0.2** |
| *Malachlemys terrapin* | 0.5 | | 0.2 |
| **Stomatopoda** | **2.8** | **8.2** | **3.9** |
| *Squilla empusa* | 2.8 | 8.2 | 3.9 |
| **Echinodermata (sea urchin)** | **0.2** | | **0.3** |
| *Arbacia punctulata* | 0.2 | | 0.3 |

**Table 15-6**. Heat map of the seasonal density (mean # hectare$^{-1}$) of select species of bony fish (*Osteichthyes*) collected in trawls pooled for geographic areas near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---"). Cells are color coded from lower (yellow) through mid (orange) to higher density (red) to visualize the relative differences between years and seasons within years.

| **Taxon (~Species)** | **Season** | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|---|
| | | **2021** | **2022** | **2023** |
| *Anchoa mitchilli* | Late-Spring | 400.6 | 429.8 | 98.1 |
| | Summer | --- | --- | 59.0 |
| | Late-Summer | 208.0 | 372.5 | 196.6 |
| *Bairdiella chrysoura* | Late-Spring | 28.8 | 5.4 | 4.6 |
| | Summer | --- | --- | 4.1 |
| | Late-Summer | 52.2 | 58.8 | 23.3 |
| *Brevoortia tyrannus* | Late-Spring | 0.4 | 53.2 | |
| | Summer | --- | --- | 0.9 |
| | Late-Summer | 0.9 | | 0.9 |
| *Centropristis striata* | Late-Spring | 26.4 | 29.9 | 3.3 |
| | Summer | --- | --- | 1.3 |
| | Late-Summer | 1.4 | 4.6 | 0.5 |
| *Lagodon rhomboides* | Late-Spring | 16.2 | 6.7 | 1.4 |
| | Summer | --- | --- | 5.1 |
| | Late-Summer | 7.7 | 254.3 | 15.3 |
| *Leiostomus xanthurus* | Late-Spring | 104.9 | 2,470.5 | 557.9 |
| | Summer | --- | --- | 456.8 |
| | Late-Summer | 201.5 | 1,202.4 | 87.7 |
| *Micropogonias undulatus* | Late-Spring | 10.9 | 17.9 | 1.5 |
| | Summer | --- | --- | 7.6 |
| | Late-Summer | 3.1 | 1.9 | 1.8 |
| *Paralichthys dentatus* | Late-Spring | 3.8 | 1.8 | 5.3 |
| | Summer | --- | --- | 3.1 |
| | Late-Summer | 1.8 | 2.3 | 1.0 |

**Table 15-7**. Heat map of the seasonal density (mean # hectare$^{-1}$) of blue crabs (*Callinectes* spp.) and penaid shrimps (multiple species pooled) collected in trawls pooled for geographic areas near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---"). Cells are color coded from lower (yellow) through mid (orange) to higher density (red) to visualize the relative differences between years and seasons within years.

| | | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|---|
| **Taxon (~Species)** | **Season** | **2021** | **2022** | **2023** |
| *Callinectes sapidus* | Late-Spring | 21.4 | 84.0 | 9.4 |
| | Summer | --- | --- | 22.9 |
| | Late-Summer | 18.5 | 39.6 | 3.3 |
| *Callinectes similis* | Late-Spring | | | |
| | Summer | --- | --- | |
| | Late-Summer | | 8.8 | 8.2 |
| *Penaid shrimp (multiple species)* | Late-Spring | 8.0 | 4.2 | 0.6 |
| | Summer | --- | --- | 1.0 |
| | Late-Summer | 40.2 | 13.1 | 23.8 |

**Table 15-8**. Summary of several community metrics (based on density of individual organisms, # hectare$^{-1}$) of species collected in trawls for three study areas near Wachapreague, VA during multiple seasons in 2021-2023. Note that there were 2 seasonal sampling efforts in 2021-2022 and 3 in 2023.

| Community Metric | Geographic Area | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| **Abundance (# hectare$^{-1}$)** | Bradford Bay | 771 | 3,636 | 949 |
| | Burton's Bay | 831 | 3,700 | 820 |
| | Wach. Inlet | 615 | 623 | 286 |
| | *Overall* | *739* | *2,653* | *685* |
| **Taxa Richness** | Bradford Bay | 25 | 36 | 26 |
| | Burton's Bay | 38 | 34 | 33 |
| | Wach. Inlet | 31 | 33 | 31 |
| | *Overall* | *54* | *50* | *46* |
| **Shannon Diversity Index (H')** | Bradford Bay | 1.37 | 1.01 | 1.39 |
| | Burton's Bay | 1.91 | 1.11 | 1.58 |
| | Wach. Inlet | 1.58 | 1.38 | 1.90 |
| | *Overall* | *1.90* | *1.19* | *1.63* |

**Table 15-9.** Summary of sizes (mm using species-specific standard measurements) of select species that were measured from trawl and seine samples near Wachapreague, VA during Late-Spring (2021-2023), Summer (2023 only) and Late-Summer (2021-2023).

| | | 2021 | | | 2022 | | | 2023 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Season** | **#** | **Size Range (mm)** | **Avg (mm)** | **#** | **Size Range (mm)** | **Avg (mm)** | **#** | **Size Range (mm)** | **Avg (mm)** |
| **Osteichthyes**[a] | | | | | | | | | | |
| *Centropristis striata* | Late-Spring | 57 | 32-105 | 73.9 | 73 | 51-122 | 84.7 | 10 | 53-85 | 69.9 |
| | Summer | --- | --- | --- | --- | --- | --- | 9 | 31-123 | 78.0 |
| | Late-Summer | 4 | 44-131 | 88.8 | 10 | 105-145 | 120.4 | 1 | 142 | 142.0 |
| *Lagodon rhomboides* | Late-Spring | 34 | 62-114 | 97.0 | 103 | 40-120 | 61.8 | 8 | 47-128 | 75.6 |
| | Summer | --- | --- | --- | --- | --- | --- | 20 | 91-120 | 103.2 |
| | Late-Summer | 17 | 118-141 | 129.6 | 228 | 105-188 | 130.0 | 33 | 118-153 | 135.6 |
| *Leiostomus xanthurus* | Late-Spring | 139 | 132-199 | 158.6 | 415 | 27-205 | 79.3 | 370 | 15-184 | 104.6 |
| | Summer | --- | --- | --- | --- | --- | --- | 342 | 87-218 | 119.7 |
| | Late-Summer | 177 | 105-204 | 127.9 | 303 | 49-220 | 120.4 | 139 | 12-210 | 130.6 |
| *Paralichthys dentatus* | Late-Spring | 22 | 35-442 | 122.1 | 5 | 59-371 | 199.6 | 11 | 61-249 | 136.5 |
| | Summer | --- | --- | --- | --- | --- | --- | 9 | 92-355 | 180.3 |
| | Late-Summer | 5 | 130-329 | 257.2 | 6 | 61-367 | 203.0 | 2 | 144-149 | 146.5 |
| **Pleocyemata (Callinectes)**[b] | | | | | | | | | | |
| *Callinectes sapidus* | Late-Spring | 76 | 11-147 | 72.1 | 265 | 19-174 | 66.6 | 45 | 19-143 | 72.0 |
| | Summer | --- | --- | --- | --- | --- | --- | 200 | 18-148 | 45.8 |
| | Late-Summer | 68 | 14-157 | 72.3 | 113 | 18-145 | 88.4 | 38 | 18-150 | 68.2 |

[a] Total centerline length

[b] Carapace width (major spine-major spine)

**Table 15-10**. Summary of the total abundace (#) and density (mean # hectare$^{-1}$) of broad taxa collected in seines (n=6 each period) near Wachapreague, VA during three sample periods (late-spring, summer and late-summer) in 2023. A blank cell indicates the absence of that taxon.

| Sample Type | | Common Name | Representative Taxonomic Grouping | 2023 Total # | | | 2023 Mean # hectare$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **Late-Spring** | **Summer** | **Late-Summer** | **Late-Spring** | **Summer** | **Late-Summer** |
| ***SEINES*** | ***All Taxa*** | | | *784* | *768* | *502* | *5,314.6* | *5,713.1* | *3,772.0* |
| | **Fish** | Teleosts | Osteichthyes | 717 | 602 | 466 | 4,851.0 | 4,403.6 | 3,485.8 |
| | | Elasmobranchs | Chondrichthyes (Elasmobranchii) | | 4 | | | 28.7 | |
| | **Crustaceans** | Blue Crabs | Pleocyemata (Callinectes) | 26 | 151 | 34 | 196.7 | 1,180.9 | 271.5 |
| | | Lady Crabs | Pleocyemata (Ovalipes) | 36 | | | 231.5 | | |
| | | Spider Crabs | Brachyura (Epialtidae) | 1 | 1 | | 8.5 | 8.5 | |
| | | Penaid Shrimps | Dendrobranchiata (Penaeidae) | | 6 | | | 57.0 | |
| | | Non-penaid Shrimps | Pleocyemata (Caridea) | 2 | | | 13.0 | | |
| | **Mollusks** | Squids | Cephalopoda | | 2 | | | 21.1 | |
| | | Snails | Gastropoda (snails) | 1 | | | 6.2 | | |
| | **Other Animals** | Mantis Shrimps | Stomatopoda | 1 | 2 | 2 | 7.6 | 13.3 | 14.7 |

**Table 15-11**. Summary of the density (mean # hectare$^{-1}$) of select broad taxa collected in seines (n=2 for each geographic area and season) near Wachapreague, VA during late-spring, summer and late-summer 2023. A blank cell indicates the absence of that taxon.

| Sample Type | Representative Taxonomic Grouping | Geographic Area | 2023 Mean # hectare$^{-1}$ | | |
|---|---|---|---|---|---|
| | | | Late-Spring | Summer | Late-Summer |
| *SEINES* | **Osteichthyes** Teleosts | Bradford Bay | 4,489.4 | 3,232.2 | 2,818.8 |
| | | Burton's Bay | 8,373.9 | 2,161.1 | 467.2 |
| | | Wach. Inlet | 1,689.8 | 7,817.6 | 7,171.4 |
| | **Pleocyemata (Callinectes)** Blue Crabs | Bradford Bay | 460.1 | 927.2 | 241.2 |
| | | Burton's Bay | 129.9 | 1,838.3 | 283.7 |
| | | Wach. Inlet | | 777.1 | 289.7 |

**Table 15-12**. Summary of the overall mean density (# hectare$^{-1}$) of select common broad taxa collected in seines (n=3 each season for 2021-2022 and n=6 each season for 2023) for three sample periods (late-spring, summer and late-summer) near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---").

| Sample Type | Broad Taxa | Common Name | Representative Taxonomic Grouping | Season | Mean # hectare$^{-1}$ | | |
|---|---|---|---|---|---|---|---|
| | | | | | 2021 | 2022 | 2023 |
| *SEINES* | Fish | Teleosts | Osteichthyes | Late-Spring | 2,822.0 | 27,498.2 | 4,851.0 |
| | | | | Summer | --- | --- | 4,403.6 |
| | | | | Late-Summer | 2,577.9 | 801.1 | 3,485.8 |
| | | Elasmobranchs | Chondrichthyes (Elasmobranchii) | Late-Spring | | 4.2 | |
| | | | | Summer | --- | --- | 28.7 |
| | | | | Late-Summer | | | |
| | Crustaceans | Blue Crabs | Pleocyemata (Callinectes) | Late-Spring | 517.7 | 774.1 | 196.7 |
| | | | | Summer | --- | --- | 1,180.9 |
| | | | | Late-Summer | 441.6 | 197.6 | 271.5 |
| | | Lady Crabs | Pleocyemata (Ovalipes) | Late-Spring | 0.0 | 148.7 | 231.5 |
| | | | | Summer | --- | --- | |
| | | | | Late-Summer | | | |
| | | Spider Crabs | Brachyura (Epialtidae) | Late-Spring | | | 8.5 |
| | | | | Summer | --- | --- | 8.5 |
| | | | | Late-Summer | | | |
| | | Penaid Shrimps | Dendrobranchiata (Penaeidae) | Late-Spring | | | |
| | | | | Summer | --- | --- | 57.0 |
| | | | | Late-Summer | 402.3 | | |
| | | Non-penaid Shrimps | Pleocyemata (Caridea) | Late-Spring | 484.6 | | 13.0 |
| | | | | Summer | --- | --- | |
| | | | | Late-Summer | | | |
| | Mollusks | Squids | Cephalopoda | Late-Spring | | | |
| | | | | Summer | --- | --- | 21.1 |
| | | | | Late-Summer | | | |
| | Other Animals | Mantis shrimps | Stomatopoda | Late-Spring | | 4.2 | 7.6 |
| | | | | Summer | --- | --- | 13.3 |
| | | | | Late-Summer | | | 14.7 |

**Table 15-13**. Summary of the density (Mean # hectare$^{-1}$) of species collected in seines within samples pooled for geographic areas (three) and seasons (two in 2021-2022 and three in 2023) near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon.

| | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|
| **Taxon (~Species)** | **2021** | **2022** | **2023** |
| ***All Taxa*** | *605.5* | *4,904.7* | *1,644.4* |
| **Osteichthyes** | **450.0** | **4,716.6** | **1,415.6** |
| *Alosa sp* | 39.1 | | 878.4 |
| *Anchoa mitchilli* | 5.8 | 54.1 | 502.9 |
| *Archosargus probatocephalus* | 19.4 | | |
| *Astroscopus guttatus* | 12.6 | | |
| *Bairdiella chrysoura* | | | 22.0 |
| *Brevoortia tyrannus* | | 11,565.3 | 7.0 |
| *Centropristis striata* | 45.7 | 34.6 | 22.7 |
| *Eucinostomus argenteus* | | 3.7 | 2.5 |
| *Eucinostomus gula* | 23.0 | | |
| *Fistularia tabacaria* | 7.9 | | |
| *Fundulus heteroclitus* | | 29.0 | 34.9 |
| *Fundulus majalis* | 194.9 | 16.6 | 11.9 |
| *Gobiosoma bosc* | 9.3 | 5.5 | |
| *Hyporhamphus meeki* | | | 2.2 |
| *Hypsoblennius hentz* | | | 2.5 |
| *Lagocephalus laevigatus* | | 3.9 | |
| *Lagodon rhomboides* | | 1,123.2 | 39.4 |
| *Leiostomus xanthurus* | 46.2 | 927.7 | 511.0 |
| *Menidia menidia* | 2,076.5 | 298.1 | 1,828.4 |
| *Menticirrhus americanus* | | | 15.9 |
| *Menticirrhus saxatilis* | 19.5 | | 7.2 |

*Table continued on next page*

**Table 15-13** (continued)

| Taxon (~Species) | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|
| *Micropogonias undulatus* | | | 2.5 |
| *Mugil cephalus* | | | 23.3 |
| *Mugil curema* | 11.5 | | 57.5 |
| *Orthopristis chrysoptera* | | 10.6 | 10.0 |
| *Paralichthys dentatus* | 72.7 | 6.1 | 5.7 |
| *Pogonias cromis* | 5.8 | 3.7 | 31.9 |
| *Prionotus carolinus* | 12.6 | 31.1 | 31.0 |
| *Scomberomorus maculatus* | | | 4.9 |
| *Sphoeroides maculatus* | | | 10.3 |
| *Sphyraena borealis* | | 2.7 | 3.5 |
| *Symphurus plagiusa* | 13.9 | 8.2 | |
| *Syngnathus fuscus* | 75.8 | 11.1 | 48.0 |
| *Synodus foetens* | | 7.4 | 119.4 |
| *Tautoga onitis* | 7.9 | 6.9 | 9.7 |
| **Chondrichthyes (Elasmobranchii)** | | | |
| *Hypanus sabinus* | | 2.1 | 6.7 |
| *Rhinoptera bonasus* | | | 2.8 |
| **Pleocyemata (Ovalipes)** | | **74.4** | **77.2** |
| *Ovalipes ocellatus* | | 74.4 | 77.2 |
| **Pleocyemata (Callinectes)** | **479.7** | **485.8** | **549.7** |
| *Callinectes sapidus* | 479.7 | 485.8 | 542.5 |
| *Callinectes similis* | | | 7.2 |
| **Pleocyemata (Cancridae)** | **9.7** | | |
| *Cancer irroratus* | 9.7 | | |
| **Brachyura (Epialtidae)** | | | **5.7** |
| *Libinia emarginata* | | | 5.7 |

*Table continued on next page*

**Table 15-13** (continued)

| Taxon (~Species) | Mean # hectare$^{-1}$ 2021 | 2022 | 2023 |
|---|---|---|---|
| **Dendrobranchiata (Penaeidae)** | **201.2** | | **19.0** |
| *Multiple species* | 201.2 | | 19.0 |
| **Pleocyemata (Caridea)** | **242.3** | | **4.3** |
| *Crangon septemspinosa* | 43.4 | | |
| *Palaemon sp* | 198.9 | | 4.3 |
| **Cephalopoda** | | | **7.0** |
| *Lolliguncula brevis* | | | 7.0 |
| **Gastropoda (snails)** | | | **2.1** |
| *Busycon carica* | | | 2.1 |
| **Stomatopoda** | | **2.1** | **11.9** |
| *Squilla empusa* | | 2.1 | 11.9 |

**Table 15-14**. Heat map of the seasonal density (mean # hectare$^{-1}$) of select species of bony fish (*Osteichthyes*) collected in seines pooled for geographic areas near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---"). Cells are color coded from lower (yellow) through mid (orange) to higher density (red) to visualize the relative differences between years and seasons within years.

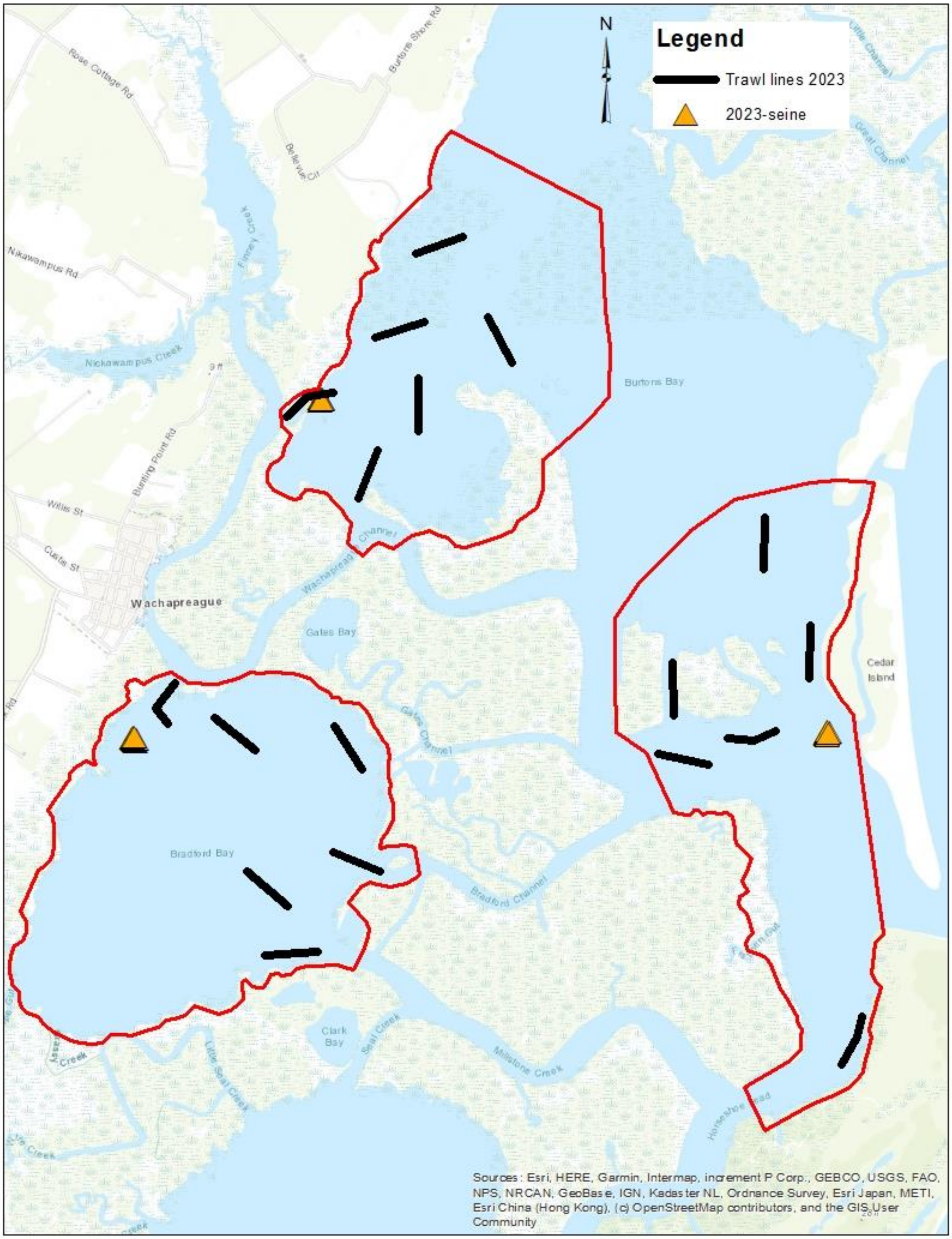
| **Taxon (~Species)** | **Season** | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|---|
| | | **2021** | **2022** | **2023** |
| *Anchoa mitchilli* | Late-Spring | | 50.3 | 444.8 |
| | Summer | --- | --- | 25.4 |
| | Late-Summer | 11.6 | 57.9 | 1,038.5 |
| *Fundulus majalis* | Late-Spring | 129.4 | 12.0 | 6.5 |
| | Summer | --- | --- | 20.5 |
| | Late-Summer | 260.4 | 21.2 | 8.8 |
| *Menidia menidia* | Late-Spring | 2,176.8 | 248.8 | 775.4 |
| | Summer | --- | --- | 2,784.7 |
| | Late-Summer | 1,976.2 | 347.4 | 1,925.1 |

**Table 15-15**. Heat map of the seasonal density (mean # hectare$^{-1}$) of blue crabs (*Callinectes* spp.) collected in seines pooled for geographic areas near Wachapreague, VA during 2021-2023. A blank cell indicates the absence of that taxon. Note that summer samples were not collected in 2021 and 2022 (noted as "---"). Cells are color coded from lower (yellow) through mid (orange) to higher density (red) to visualize the relative differences between years and seasons within years.

| **Taxon (~Species)** | **Season** | **Mean # hectare$^{-1}$** | | |
|---|---|---|---|---|
| | | **2021** | **2022** | **2023** |
| *Callinectes sapidus* | Late-Spring | 517.7 | 774.1 | 196.7 |
| | Summer | --- | --- | 1,180.9 |
| | Late-Summer | 441.6 | 197.6 | 249.8 |

**Table 15-16**. Summary of several community metrics (based on density of individual organisms, # hectare-1) of species collected in seines for three study areas near Wachapreague, VA during two seasons in 2021-2023. Note that there were 2 seasonal sampling efforts in 2021-2022 and 3 in 2023.

| Community Metric | Geographic Area | 2021 | 2022 | 2023 |
|---|---|---|---|---|
| **Abundance (# hectare$^{-1}$)** | Bradford Bay | 3,774 | 2,998 | 4,137 |
| | Burton's Bay | 2,242 | 39,244 | 4,583 |
| | Wach. Inlet | 4,882 | 2,001 | 6,117 |
| | *Overall* | *3,633* | *14,748* | *4,946* |
| **Taxa Richness** | Bradford Bay | 14 | 18 | 24 |
| | Burton's Bay | 12 | 17 | 25 |
| | Wach. Inlet | 14 | 12 | 27 |
| | *Overall* | *25* | *25* | *41* |
| **Shannon Diversity Index (H')** | Bradford Bay | 1.35 | 1.72 | 1.91 |
| | Burton's Bay | 2.00 | 0.57 | 1.73 |
| | Wach. Inlet | 1.08 | 1.71 | 1.45 |
| | *Overall* | *1.68* | *0.90* | *2.07* |



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

**Figure 15-1** Locations of 18 trawl (black lines) and 3 seine (orange triangles) monitoring sites near Wachapreague, VA for 2023 (red polygons denote the ESL-EMP study areas).

**Figure 15-2** Beach seine sampling.

# ***Section 4*: *Historic Comparisons***

# Chapter 16. Historic Comparisons: Water Quality

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### Introduction

Water temperature plays a crucial role in the marine environment by influencing the physical and chemical properties of water that are critical to marine life. Water temperature directly impacts water chemistry by influencing the dissolution of gases and solids in water, affecting dissolved oxygen vital for respiration and dissolved silica essential to the growth of microalgae and diatoms. Additionally, water temperature impacts pH which is important for the physiology and development of marine organisms, significant for calcium carbonate structures of shellfish, snails, and corals, and is known to influence fish behavior and sensory responses (Cattano et al. 2018).

In addition to the effects on water chemistry, water temperature also influences all biological processes that occur within an aquatic environment and drives the distribution and abundance of biota. Water temperature dictates habitat boundaries and geographic range distributions based on acclimation and tolerance adaptations that determine optimal temperatures for all living things. Metabolic processes of organisms are regulated by their optimal temperature limits. Both short and long-term variations in temperature influence organism behaviors, migratory patterns, reproduction, growth, and survival.

Historical water quality records can be used to differentiate seasonal or short-term variability vs. long-term changes within aquatic ecosystems. Although VIMS ESL began continuous water quality monitoring in Wachapreague in 2016 (see Chapter 3), there are 2 additional sources of historical water temperature data preceding these efforts. Both located at ESL, the Castagna Shellfish Research Hatchery has been recording daily water temperature readings since the 1960s, and the NOAA Data Buoy Center has been continuously monitoring water temperature since 2005. Collectively, these historical records can be used to observe water temperature fluctuations in Wachapreague over the past 60+ years.

### Study Area & Methods

Data from ESL’s Wachapreague water quality monitoring station has been presented annually in ESL’s Ecological Monitoring Reports (Ross and Snyder 2020-present), so the focus of this chapter is to present the 2 additional sources of historical water temperature data. The

Castagna Shellfish Research Hatchery and NOAA's monitoring site (Station WAHV2) are located at VIMS ESL in Wachapreague, Virginia. Both sources measure water quality from the Wachapreague Channel and collect data within 200 ft. of each other. The Castagna Shellfish Research Hatchery Archive consists of 1 manually recorded data point per day since 1961 (37°36'29.4624" N 75°41'9.5604" W). The hatchery archive readings are typically collected in the morning, capturing data across varying tidal cycles throughout the year. Daily measurements were recorded Monday-Friday using a thermometer or electronic handheld meter to sample the water conditions in ESL's boat basin. Since 2007, NOAA's Station WAHV2 has continuously recorded water temperature data at 10-minute intervals from a fixed depth (2005 data available at 1-hour intervals). NOAA's Station WAHV2 is co-located with ESL's Wachapreague water quality station, positioned off the Seawater Laboratory pier (37°36'27.6912" N 75°41'8.9124" W). The correlation ($R^2 = 0.9994$) of water temperature readings between ESL's Wachapreague Station and NOAA's Station WAHV2 is discussed in the 2018-2019 Ecological Monitoring Program Report (Ross and Snyder, 2020; see Chapter 2-1). Archived data from the Castagna Shellfish Research Hatchery (1961-2023) is available upon request (contact Darian Kelley at dkelley@vims.edu), and the archived data from NOAA's Station WAHV2 (2005, 2007-2023) can be found on the NOAA Data Buoy Center website (https://www.ndbc.noaa.gov/station_history.php?station=wahv2).

Historical data from the Castagna Shellfish Research Hatchery and NOAA's Station WAHV2 were consolidated using Microsoft Excel for comparison. Castagna Shellfish Research Hatchery data from 1961 (July-Dec) and 2023 (Jan-Aug), and NOAA WAHV2 data prior to 2011 (2005-2010) was omitted from the figures and calculations in this report, because there was <85% of expected readings for a full year and/or the data was not dispersed across all months of the year.

## Results & Discussion

All data from the Castagna Shellfish Research Hatchery and NOAA's Station WAHV2 was plotted for visualization and analysis (Fig. 16-1). The full historical record from Station WAHV2 exceeds the row limit using Excel, so daily average temperatures were calculated for days when >85% of expected readings were recorded. Based on the slopes of the linear regressions in Fig. 16-1, the Castagna Shellfish Research Hatchery archive shows a daily temperature increase of 0.00008°C since 1962 and the NOAA WAHV2 data shows a 0.0003°C increase since 2011. To investigate the difference between the daily temperature increase calculations between the two sources, the data from Fig. 16-1 was consolidated onto the same graph for 2011-2023 (Fig. 16-2). When the data is compared for the same time period, the daily temperature increase is the same between both sources (0.0003°C). This suggests that the water temperature in Wachapreague Channel has been increasing more rapidly within the past ~12-13 years than it had been since the 1960s. This observation of an accelerated increase in water temperature over the past decade is validated by current ocean surface temperature research.

According to the United States Environmental Protection Agency (EPA) website, the ocean surface temperature has been consistently higher during the past 3 decades than any other time since 1880 (https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature). Additionally, Garcia-Soto et al. (2021) compared 4 ocean surface temperature datasets from 1900-2019 to reveal the rate of global ocean surface warming during 2010-2019 was 4.5x higher than the 120-year long term mean.

To examine the comparability of the two datasets, the daily measurements from the Castagna Shellfish Research Hatchery were compared with the NOAA daily average water temperature during all days when data was available from both sources from 2011-2021 (Fig. 16-3). An $R^2$ value of 0.9782 confirms a strong similarity between the overlapping days. The average daily variation between the manually recorded datapoint from the Castagna Shellfish Research Hatchery and the NOAA daily average water temperature ($avgWT_{NOAA} – WT_{CSRH}$) is 0.70°C ± 1.24°C on overlapping days from 2011-2021 (n=2159 days). This positive value indicates that the average daily water temperature calculated for NOAA’s Station WAHV2 tends to be higher than the single Castagna Shellfish Research Hatchery data point. This deviation is likely explained by the Castagna Shellfish Research Hatchery data point being collected in the morning before the water and air temperature are affected by the heat from the sun; whereas, the NOAA data captures data throughout the day.

Using these historical datasets, the changes in Wachapreague water temperature overtime can be observed (Table 16-1). Based on the daily change from the regressions in Fig. 16-1, the Wachapreague water temperature has increased 0.03°C/year and 0.29°C/decade from 1962-2022 with a total increase of 1.78°C in temperature over 61 years. Similarly, Hinson et al. (2021) reported an increase of 0.02±0.02°C/year and 0.24±0.15°C/decade in the Chesapeake Bay from the late 1980s – late 2010s. Despite being more than 3x the reported increase in ocean surface temperature (0.08°C/decade from 1901-2020 reported on the EPA website), the decadal increases for the Wachapreague Channel and Chesapeake Bay are comparable to the reported 0.18-0.31°C/decade temperature increase of the Northeast Continental Shelf for 1968-2018 (Friedland et al., 2020). When observing the change in temperature in the Wachapreague Channel over a shorter timeframe (2011-2023), the increase changes to 0.11°C/year and 1.10°C/decade, which also aligns with the Northeast Continental Shelf increase of 0.26-1.49°C/decade for 2004-2018 reported by Friedland et al. (2020).

To summarize the historical data, yearly minimum, maximum, average, and standard deviation values were calculated for both sources for years when >85% of expected readings were collected (Fig.16-4). From 1963-2015, the yearly average minimum, maximum, and average temperatures captured by the Castagna Shellfish Research Hatchery were 0.75±0.86°C, 29.42±1.20°C, and 15.95±0.67°C respectively. From 2011-2023, the yearly average minimum, maximum, and average temperatures observed by the NOAA station were 0.41±0.47°C, 32.24±.0.55°C, and 17.10±.37°C, respectively.

Since the water temperature data for the Castagna Shellfish Research Hatchery is comparable to the NOAA data, and the NOAA data is comparable to ESL's Wachapreague monitoring station, historical water temperature records from the Castagna Shellfish Research Hatchery can be used as background context for current and future EMP temperature comparisons. In addition to water temperature, the Castagna Shellfish Research Hatchery archive contains historical salinity and air temperature since the 1960s, and dissolved oxygen, pH, and barometric pressure since 2015, and the NOAA records include water level, wind direction, wind speed, gusts, atmospheric pressure, and air temperature.

Observing the changes in Wachapreague water temperature overtime would not be possible without the historical records from the Castagna Shellfish Research Hatchery and NOAA's Station WAHV2. To enhance the historical records for the Wachapreague Channel, ESL's Wachapreague monitoring station continuously monitors water temperature, salinity, pH, dissolved oxygen, turbidity, chlorophyll-a, and blue green algae phycoerythrin (BGA-PE) levels at 15-minute intervals. Moving forward, ESL's continuous monitoring data can be utilized for historical/long-term analyses on prevalent topics, such as ocean acidification and changes in dissolved oxygen, for monitoring climate change.

## Acknowledgements

I would like to thank PG Ross for conceptualization of this chapter and assistance with methodology and interpretation of analyses. I would also like to thank the two sources that provided data for this historical comparison: the Castagna Shellfish Research Hatchery and the National Oceanic and Atmospheric Administration (NOAA) Data Buoy Center.

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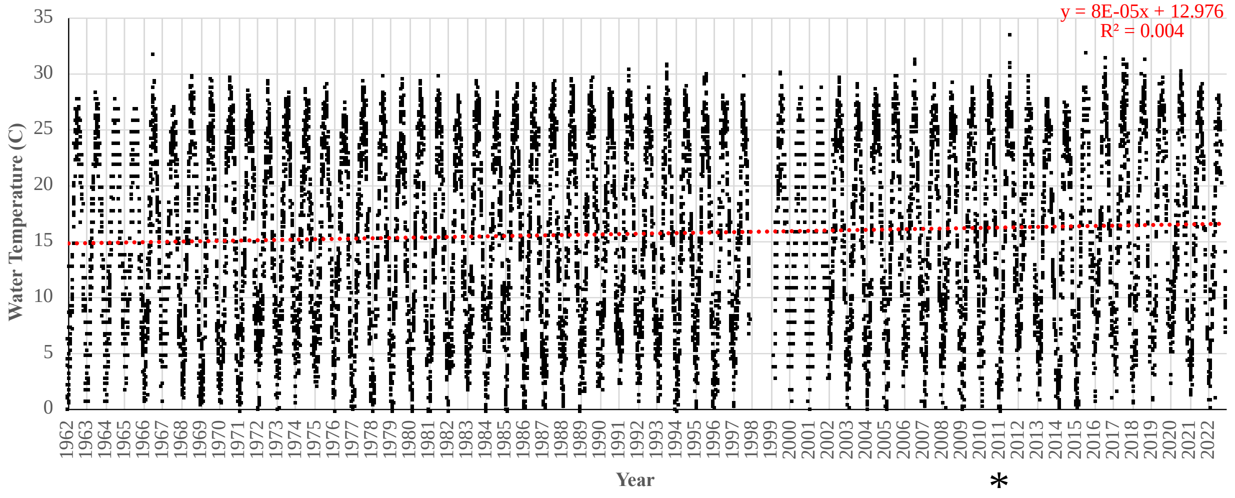
**Table 16-1.** Wachapreague water temperature change based on the historical records of the Castagna Shellfish Research Hatchery and NOAA Station WAHV2.

| Data source | Date range | Daily change (°C) | Yearly change (°C) | Decadal change (°C) |
|---|---|---|---|---|
| Castagna Shellfish Research Hatchery | January 1962 - December 2022 | 0.00008 | 0.03 | 0.29 |
| | January 2011 - December 2022 | 0.00030 | 0.11 | 1.10 |
| NOAA WAHV2 | January 2011 - December 2023 | 0.00030 | 0.11 | 1.10 |

A) Castagna Shellfish Research Hatchery Archive



B) NOAA Data Buoy Center Station WAHV2

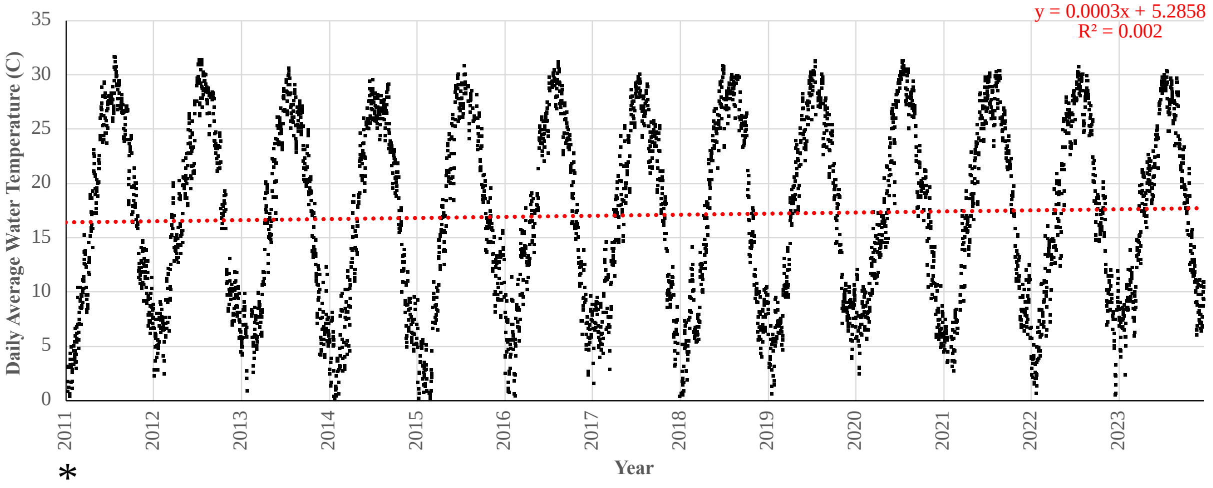


**Figure 16-1** A) All water temperature data from the Castagna Shellfish Research Hatchery Archive during 1962-2022 and B) Daily average water temperature from NOAA Station WAHV2 during 2011-2023 for days when >85% of expected readings were recorded. The "*" symbols denote where the data sets begin to overlap.

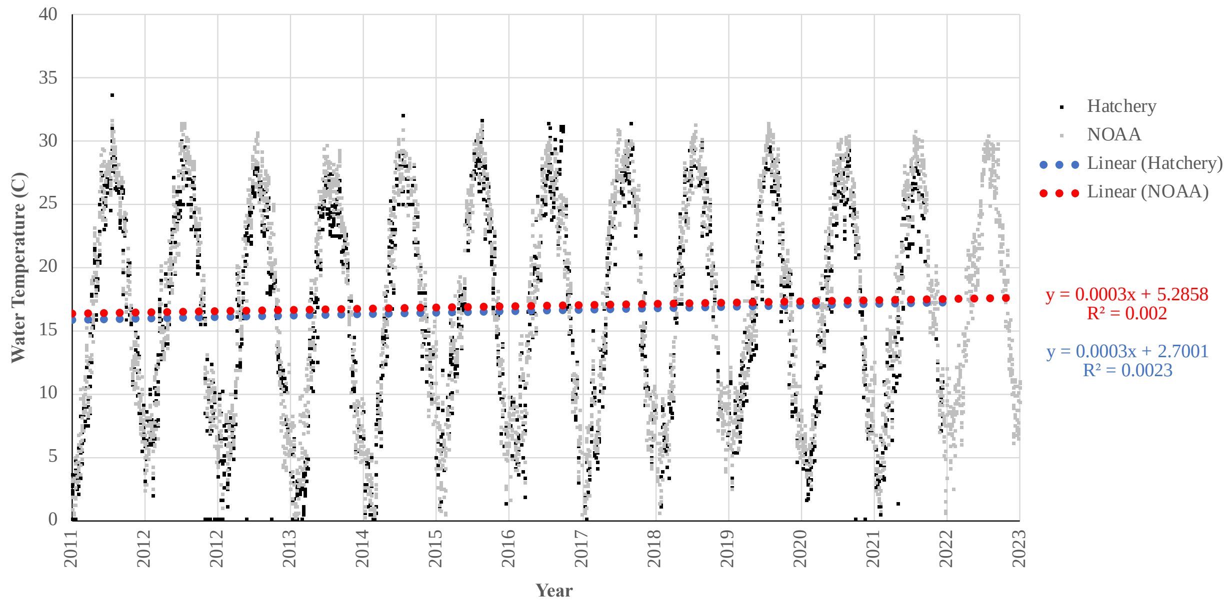


**Figure 16-2** 2011-2023 water temperature data from the Castagna Shellfish Research Hatchery Archive and daily average water temperature from NOAA Station WAHV2 for days when >85% of expected readings were recorded.

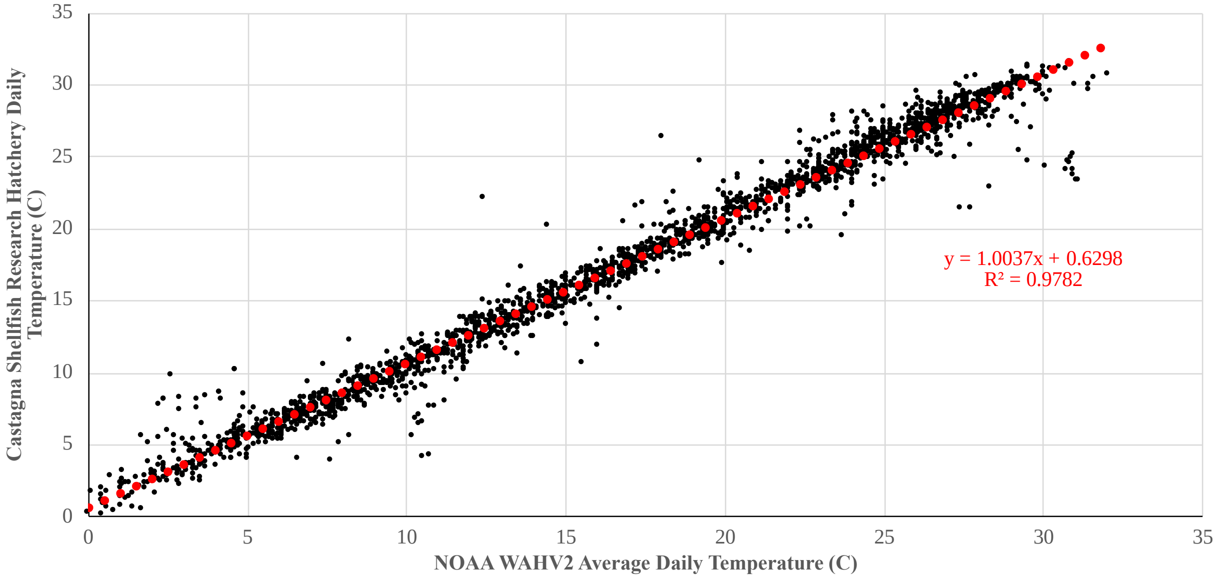
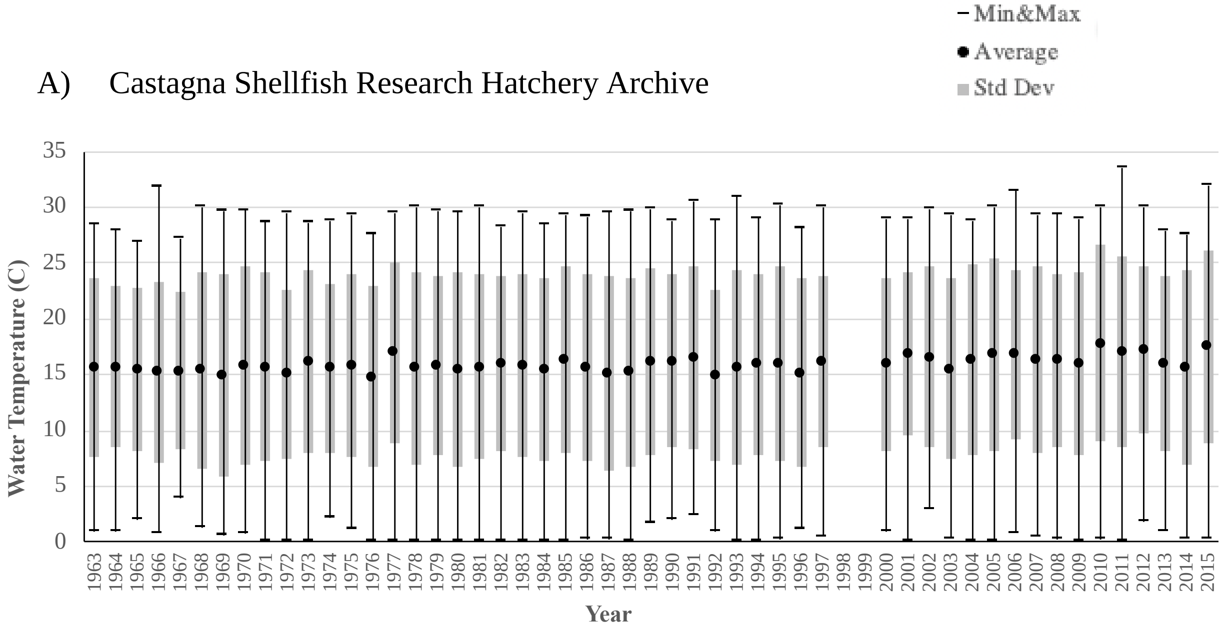


**Figure 16-3** Comparison of the Castagna Shellfish Research Hatchery daily water temperature measurement and NOAA Station WAHV2 daily average water temperature ($avgWT_{NOAA}, WT_{CSRH}$) from 2011-2021 on overlapping days when data was available from both sources (n=2159 days). NOAA daily average temperatures were calculated only for days when >85% of expected readings were recorded.

A) Castagna Shellfish Research Hatchery Archive



C) NOAA Data Buoy Center Station WAHV2

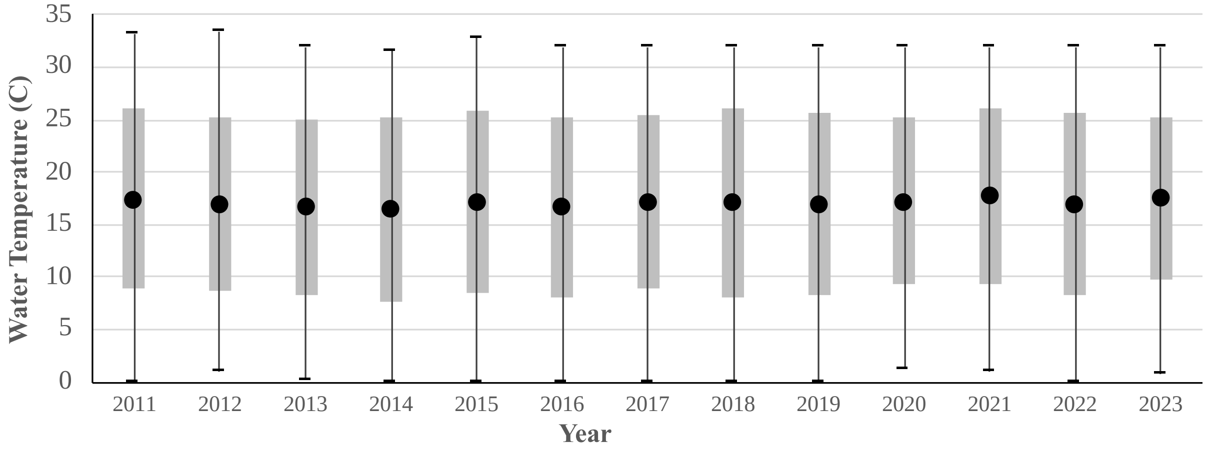


**Figure 16-4** Yearly minimums, maximums, averages, and standard deviations for the A) Castagna Shellfish Research Hatchery Archive and B) NOAA Station WAHV2. Values were calculated for years when >85% of expected readings were recorded. Since the Hatchery readings are only documented Monday-Friday, 85% of expected Hatchery readings was considered 221/year (60% of a full year); whereas 85% of NOAA readings was considered 74460/year.