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A Site profile of the Chesapeake Bay National Estuarine Research Reserve in Virginia

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A SITE PROFILE OF THE CHESAPEAKE BAY NATIONAL ESTUARINE RESEARCH RESERVE IN VIRGINIA

Edited by

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Preface

The purpose of this Site Profile is to review the existing state of knowledge for important geological, physical, chemical and biological components of the York River ecosystem within which the four individual reserve sites of Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) are located. It is developed from a combination of literature and field research studies that provide an overall picture of the Reserve in terms of its ecosystem, management, and research needs. It is not designed to be a complete review of all the ecosystem components, but rather it is designed to provide, through a series of reviews, an overview of the York system to students, researchers, resource managers and the general public, and to provide a system context for the individual reserve sites located within the York River estuary. It starts first with an Introduction to the Reserve including its mission and objectives. Next the geological, physical and water quality setting of the individual reserve sites and the overall York River ecosystem are described. Scientific overviews of three important primary producer components and habitats within the region (phytoplankton, wetlands and submerged aquatic vegetation) are presented next. Secondary and higher trophic components (zooplankton, benthos, and fishes) are then reviewed, and finally the principal reptiles, amphibians, birds and mammals that are associated with the local estuarine waters are described. This Site Profile concludes with a description of the Reserve's ongoing research and monitoring programs, the Reserve goals and strategies, and an overview of research and monitoring needs for the future.

Acknowledgements

Funds for the development of this Site Profile were provided by the National Oceanographic and Atmospheric Administration's Estuarine Reserves Division and The Virginia Institute of Marine Science (VIMS), School of Marine Science, College of William and Mary. The editors gratefully acknowledge the major contributions of authors of the individual reviews, without whom this Site Profile could not have been completed. Each provided information from their extensive and detailed background of knowledge of the individual components comprising the complex York River estuarine ecosystem. We were most fortunate to be able to call upon the many scientists located at VIMS, the College of William and Mary, Christopher Newport University and Old Dominion University to complete this work.

Dr. Carl H. Hobbs, a long time researcher and Associate Professor at VIMS in the Department of Physical Sciences, provided the overview of the Geology of the Reserve. His primary research interests are in the Quaternary geology of Chesapeake Bay and the mid-Atlantic inner continental shelf and coastal plain.

Dr. Carl T. Friedrichs, a Professor of Marine Science, also in the Department of Physical Sciences at VIMS, authored the review of the Physical Processes and Sediment Transport in the system. His long term research goals are to better understand the fundamental aspects of coastal and estuarine physics which control sediment and other material fluxes at time-and length-scales important to geology, biogeochemistry, and ecology.

Dr. William G. Reay, co-editor and author of the review of Water Quality in the York River and co-author of the Introduction to the Reserve and Research the Research and Monitoring Programs in of the Reserve, is an Associate Research Professor in the Department of Physical Sciences at VIMS and Director of the Chesapeake Bay National Estuarine Research Reserve in Virginia. His primary research interest is in the area of watershed hydrology and nutrient dynamics with an emphasis on the study of groundwater-surface water interactions. He is also involved in the development and implementation of shallow water monitoring programs and their integration into ocean and coastal observation systems.

Dr. Kenneth A. Moore, co-editor and author of the review of submerged aquatic vegetation and co-author of the Introduction to the Reserve and Research the Research and Monitoring Programs in of the Reserve, is a Professor of Marine Science in the Department of Biological Sciences at VIMS and Research Coordinator of the CBNERRVA. His research studies have focused on the ecology of estuarine and coastal shallow water environments, especially those vegetated with marshes, seagrasses and other submersed aquatic vegetation. Specifically, he has studied the relationships between these aquatic macrophyte systems and environmental factors including water quality conditions that limit their growth, survival and restoration. His principal responsibilities at CBNERRVA are to manage the System-wide Monitoring Program and research within the reserve sites.

Dr. James E. Perry III and Dr. Robert B. Atkinson are authors of the overview of Tidal Marshes of the York River System and the individual reserve sites. Dr. Perry is a Professor of Marine Science in the Department of Biological Sciences at VIMS. His primary research interests involve monitoring stress and documenting long-term changes in vascular plant communities of tidal and non-tidal wetlands, and the relationship of those changes to changes in environmental parameters within watersheds. Dr. Atkinson is a Professor on the Graduate Faculty of the Department Biology, Chemistry and Environmental Science at Christopher Newport University. His primary research area is the restoration of damaged ecosystems.

Dr. Harold G. Marshall who authored the overview of the Phytoplankton of the York River presently holds a Professor Emeritus position at Old Dominion University His research interests have emphasized phytoplankton studies in diverse habitats including: freshwater environments, the continental shelf waters of eastern United States, and the Chesapeake Bay and its tidal rivers. In addition, he has studied harmful bloom and toxin producing algal species. He is a past recipient of Old Dominion University's Tonelson Distinguished Faculty Award, the University's Faculty Research Award, and is a Fellow and past President of the Virginia Academy of Science.

Dr. Deborah K. Steinberg and Dr. Robert H. Condon co-authored the review of Zooplankton in the York River System. Dr. Steinberg is a Professor of Marine Science in the Department of Biological Sciences at VIMS. Her research interests are in zooplankton ecology and physiology, coastal and deep-sea food webs, nutrient cycling, and marine detritus ("marine snow"). Dr. Robert Condon is a graduate of the Department of Biological Sciences at VIMS. His doctoral research focused on the ecology of gelatinous zooplankton in the Chesapeake Bay.

David J. Gillett and Dr. Linda C. Schaffner co-authored the review of the Benthos of the York River System. David Gillett is a doctoral candidate and NERRS Graduate Research Fellow. His current research is on food web energetics of macrobenthic invertebrate communities. Dr. Linda Schaffner is a Professor of Marine Science in the Department of Biological Sciences at VIMS. Her research program focuses on the ecology of benthic systems and benthic processes of estuarine and coastal ecosystems. Specifically she is interested in how natural processes and anthropogenic alterations of coastal ecosystems influence the structure and function of benthic communities, including meiofauna, macrofauna and associated nekton, via processes such as disturbance (mortality) and recruitment.

Dr. Mary C. Fabrizio, Amanda Hewitt, and Julia Ellis are co-authors of Fisheries of the York River System. Dr. Fabrizio is an Associate Professor of Marine Science in the Department of Fisheries Science at VIMS. Her specialties include quantitative fisheries ecology with particular emphasis on modeling long-term trends from fisheries survey data and estimating habitat use and occupancy using mark-recapture models. She is currently leader of two spatially extensive and long-term survey programs at VIMS aimed at estimating recruitment of fishes, including the Juvenile Fish Survey and the Striped Bass Seine Survey. Amanda Hewitt is a former Marine Scientist who was a co-principal investigator on the Virginia Juvenile Striped Bass Survey in the Department of Fisheries Science at VIMS. Julia Ellis is a former Marine Scientist with the

Juvenile Fish Survey in the Department of Fisheries Science at VIMS. Other VIMS scientists contributed important information for this chapter. Patrick McGrath, a Ph.D. candidate in the Department of Fisheries Science at VIMS contributed information on longnose gar. Dr.Christopher Hager, a Fisheries Specialist at VIMS in the Virginia Sea Grant Program, provided information on Atlantic sturgeon; Chris is working on several projects to increase sturgeon populations in Virginia's tributaries. Paul Gerdes, a Marine Scientist and the Nunnally Ichthyological Collections Manager in the Department of Fisheries Science at VIMS, contributed to the section on sharks and rays. David Hewitt, a Ph.D. graduate from the Department of Fisheries Science at VIMS, provided information on the blue crab; David's dissertation work focused on population dynamics and stock assessment of blue crab in the Chesapeake Bay and was supported by the Willard A. Van Engel Fellowship.

Joseph Brown and Sandra Erdle co-authored the overview of the reptiles, amphibians, birds and mammals associated with the York River. Joseph Brown is a life-long local naturalist and Public Services Assistant at the Hargis Library at VIMS. Sandra Erdle, the Coastal Training Program Coordinator at CBNERRVA, is knowledgeable about local mammals and wildlife; information she gained from many years of research and study at Virginia Commonwealth University, and the Department of Conservation and Recreation, Division of Natural Heritage.

This Site Profile benefited greatly from an external peer-review process including scientists at NOAA's Estuarine Reserves Division (ERD), Silver Spring, Maryland. Special thanks to Diane Walker and Susan Stein of VIMS for editorial and layout assistance. Work on this publication was conducted under an award from the ERD to the CBNERRVA.

Introduction to the Chesapeake Bay National Estuarine Research Reserve in Virginia

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ABSTRACT

Designated in 1991, CBNERRVA established a multi-component system along the salinity gradient of the York River estuary that encompassed the diverse collection of habitats found within the southern Chesapeake Bay subregion. With its two principal tributaries, the Pamunkey and Mattaponi Rivers, the York River is the Bay's fifth largest tributary in terms of flow and watershed area. The York River estuary is classified as a microtidal, partially mixed estuary. Tidal range varies from 0.7 m and at its mouth to over 1 m in the upper freshwater tributary reaches and salinity distribution ranges from tidal freshwater to polyhaline regimes. Land use is predominantly rural in nature with forest (61%) and agricultural lands (21%) being the dominant land cover; wetlands comprise approximately 7% of the basins area. Reserve components include: (1) Goodwin Islands (148 ha), an archipelago of polyhaline salt-marsh islands surrounded by inter-tidal flats, extensive submerged aquatic vegetation beds, and shallow open estuarine waters near mouth of the York River; (2) Catlett Islands (220 ha), consisting of multiple parallel ridges of forested wetland hammocks, maritime-forest uplands, and emergent mesohaline salt marshes; (3) Taskinas Creek (433 ha), containing non-tidal feeder streams that drain oak-hickory forests, maple-gum-ash swamps and freshwater marshes which transition into tidal oligo and mesohaline salt marshes; and (4) Sweet Hall Marsh (443 ha), an extensive tidal freshwater-oligohaline marsh ecosystem located in the Pamunkey River, one of two major tributaries of the York River. CBNERRVA manages these reserves to support informed management of coastal resources by supporting research that advances the scientific understanding of watershed and estuarine systems, highlighting proper stewardship of coastal resources, and improving general public and professional literacy through education and training programs.

HISTORICAL OVERVIEW

In 1988, the Chesapeake Executive Council, made up of the governors of Virginia, Maryland, and Pennsylvania, the mayor of the District of Columbia, the chair of the Chesapeake Bay Commission and the administrator for the Environmental Protection Agency (USEPA), established as one of the Bay region's research support priorities the establishment of a system of research reserves which will provide the research community with sites for long-term habitat focused research that will be protected as far as possible from immediate threats from development (Chesapeake Executive Council, 1988). It is within this context that the Commonwealth of Virginia began it's planning for the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA or Reserve). The Virginia Institute of Marine Science (VIMS)/College of William and Mary was designated by the Governor to take the lead role in establishing a suitable research reserve system for the Commonwealth.

Based on a salinity and tributary segmentation scheme, it was originally envisioned that CBNERRVA might eventually include more than 20 components. Because of the high number of potential components, designation of CBNERRVA sites was to occur in a phased manner. Phases were designated as (I) York River basin (Figure 1), (II) Rappahannock and Potomac River basins, (III) James River basin and western shore of Chesapeake Bay, and (IV) the Bay-side Eastern Shore of Chesapeake Bay. The York River basin components were designated in 1991 and CBNERRVA became the 18th reserve within the national system. Based on a number of concerns, which included staff and resource limitations, expansion of CBNERRVA outside the York River system has been suspended at this time. It is anticipated that when fully implemented, the Virginia Estuarine and Coastal Research Reserve System (VECRRS) will achieve many of the goals originally envisioned with the proposed phased expansion of the Reserve.

Mission Statement

The mission of CBNERRVA is to:

preserve a network of reserves that represent the diversity of coastal ecosystems found within the York River estuary and its principal tidal tributaries and manage these reserves to support informed management of coastal resources.

To fulfill its mission, the Reserve advances scientific understanding of watershed and estuarine systems, conducts education and training programs, conserves coastal resources and provides advisory service. The Reserve's mission complements the three-part mission of the VIMS to conduct interdisciplinary research in coastal ocean and estuarine science, educate students and citizens, and provide advisory service to policy makers, industry, and the public.

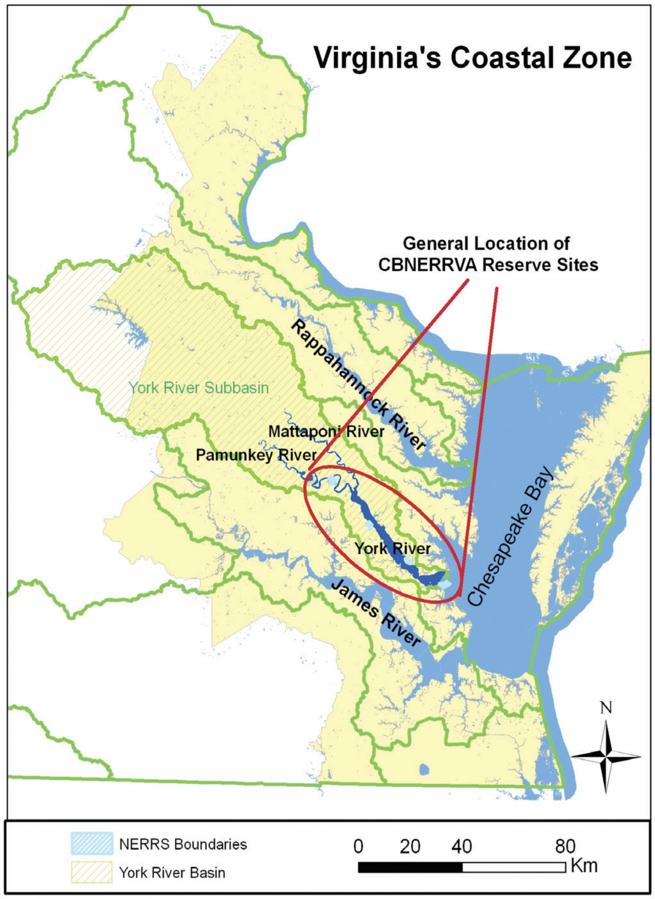

Figure 1. Coastal zone of Virginia highlighting the York River drainage basin.

Chesapeake Bay Management Issues and CBNERRVA Focus Areas (2008-2012)

Degradation of marine and estuarine environments is of global concern and the Chesapeake Bay system is no exception. A growing population along with associated land use changes are primary factors causing water quality and habitat degradation in the Bay's watershed, its tributaries and the Bay proper. Key management issues and threats to the Bay system include:

- Excess sediments which result in degraded habitat, reduce water clarity, and serve to transport toxic materials, pathogens and nutrients to water resources;
- Excess nutrients, both nitrogen and phosphorus, that stimulate algal blooms and lead to oxygen deprived waters and reduced water clarity;
- Introduction of toxic chemicals (e.g., mercury, PCBs, pesticides) and associated health impacts on wildlife and humans;
- Loss and/or degradation of key habitats (e.g., submerged aquatic vegetation, wetlands, riparian forests, oyster reefs) that provide a wide variety of critical ecosystem services; and
- Declining finfish and shellfish populations due to overfishing, disease issues and habitat loss.

CBNERRVA has developed four focus areas that address national, regional and local issues. Cutting across specific program boundaries, issue focus areas allow the Reserve to address key management concerns in a more integrated and comprehensive manner. Primary focus areas directing Reserve programs that provide direct support for coastal resource management include:

- Functions and linkages of land-margin ecosystems;
- Ecosystem vulnerability to climate (Figure 2) and human-induced stressors;
- Water quality and aquatic stressors; and
- Integrated ocean observing systems.

Figure 2. Episodic large storms (Tropical Storm Ernesto, 9/1/2006) impact Bay resources and coastal communities. Photo credit: William Reay.

RESERVE SETTING

Chesapeake Bay

Chesapeake Bay was first named "Chesepiooc" or "Great Shellfish Bay" by Native Americans for its bounty of crabs, oysters and other shellfish. As the nation's largest estuary, it remains today as a national treasure and one of the most productive in the world. Formed from a drowned river valley by melting glaciers over 12,000 years ago, the Chesapeake Bay main-stem stretches approximately 305 km (190 mi) from Havre de Grace, Maryland to Norfolk, Virginia. The Bay and its tributaries have approximately 18,700 km (11,680 mi) of shoreline and a water area of 11,600 km^2 (4,480 mi^2)(Cronin, 1971). Despite its vast size, Chesapeake Bay is relatively shallow with an average depth on the order of 6.4 m (21 ft)(Cronin, 1971); 20 percent of the Bay exhibits water depths less than 2.1 m (7 ft) and 10 percent exhibits water depths less than 0.9 m (3 ft).

The Bay receives about half of its water volume from the Atlantic Ocean with the rest entering from surface waters (rivers and streams), ground water and direct precipitation. The Bay's watershed, on the order of 165,700 km^2 (64,000 mi^2), incorporates parts of six states (i.e., New York, Pennsylvania, West Virginia, Delaware, Maryland, and Virginia) and the District of Columbia. Major river systems flowing into the Bay include the Susquehanna, Patuxent, Potomac, Rappahannock, York, and James River, with the Susquehanna providing about half of the freshwater input. The large extent of the Bay, its tributaries, and watershed, and the mixing of fresh and high salinity ocean water results in a large diversity of aquatic, intertidal, riparian and upland habitats. The Bay, its tributaries, and its watershed represents a complex ecosystem that supports over 3,600 species of plants and animals including approximately 350 species of finfish, 170 species of shellfish, 200 species of birds and waterfowl, and over 2,700 plant species (USEPA/CBP; http://www.chesapeakebay.net/status.cfm).

In addition to natural resources, the Bay watershed is home to more than 15 million people and is projected to grow to 18 million by 2020 (http://www.chesapeakebay.net/pop.htm). Approximately 70 and 90 percent of Virginia's and Maryland's population live within coastal counties, respectively (Crossett *et al.*, 2004). Throughout modern history, the Chesapeake Bay and its tributaries have help sustain the regions economy through commercial and recreational fisheries and other opportunities, and served as a hub for shipping and commerce. The Bay annually produces 227 million kg (500 million lbs) of seafood and contains two (i.e., Baltimore and Hampton Roads) of the five major North Atlantic ports in the U.S. (USEPA/CBP; http://www.chesapeakebay.net/status.cfm). Agriculture and related activities continue to play a very important role with respect to land use and economics within the Bay watershed. On an aerial basis, agricultural lands represent approximately thirty percent of the Bay's watershed. A growing tourism trade, service and high-technology jobs, and a strong military presence all continue to support the regions economy.

York River Geographical Description

As the nation's largest estuary, Chesapeake Bay contains a diverse collection of habitats and salinity regimes. In order to incorporate the diversity of habitats in the southern Chesapeake Bay subregion, CBNERRVA established a multi-component system along the salinity gradient of the York River estuary. The York River estuary is the Bay's fifth largest tributary in terms of flow and watershed area on the order of 6900 km^2 (2662 mi^2). The York River basin is located within Virginia's Coastal Plain and Piedmont physiographic provinces and includes all of the land draining into the Mattaponi, Pamunkey and York Rivers. Land use is predominantly rural in nature with forest cover accounting for 61 percent of the basin's cover, agricultural lands accounting for 21 percent, developed lands 2 percent, wetlands 7 percent, barren lands 1 percent and water accounting for the remaining 8 percent (Chesapeake Bay Program watershed profiles: http://www.chesapeakebay.net)(Figure 3). Percentage of impervious surfaces, a component of developed lands, is on the order of 1 percent. Starting from the headwater regions, the York River basin includes all or portions of the following counties: Albemarle, Orange, Louisa, Fluvanna, Spotsylvania, Goochland, Hanover, Caroline, Essex, King William, King and Queen, New Kent, James City, Gloucester and York. Year 2000 population estimates for the York River watershed was 372,500 (EPA/CBP Watershed Profiles; www.chesapeakebay.net) and is projected to reach 452,000 in the next twenty years. Population centers within the watershed include Poquoson, Gloucester Point, Ashland, West Point and Spotsylvania Courthouse. While there are currently no major metropolitan areas contained within the watershed, growth from Fredericksburg, Richmond and Hampton Roads is impacting the region.

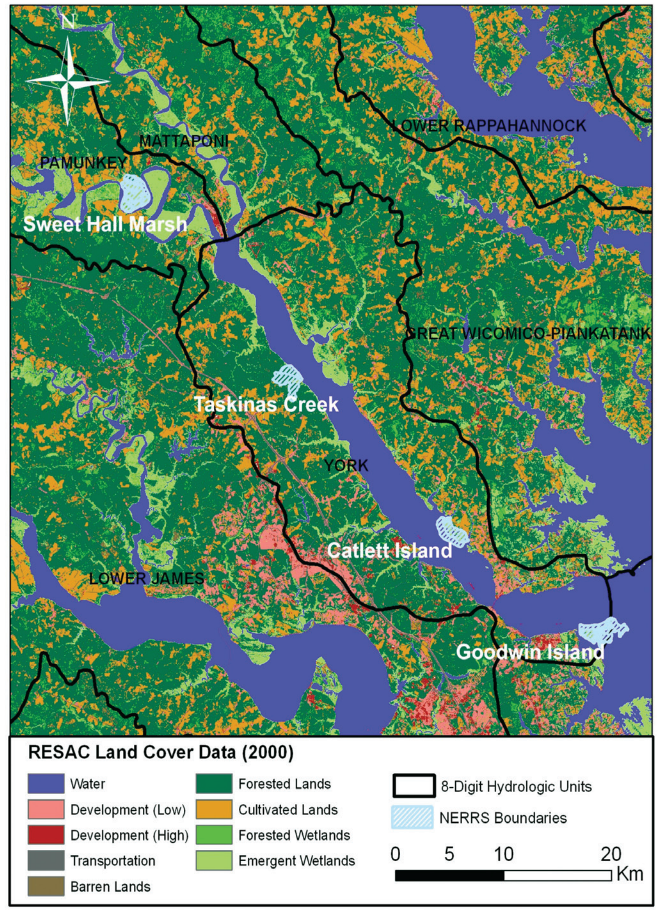

Figure 3. Reserve component locations and land-use within the York River basin and surrounding lands.

The York River receives freshwater from its two major tributaries whose confluence is at West Point located approximately 52 km (32 mi) from the rivers mouth near the Goodwin Islands component of the Reserve. Long-term daily mean streamflow is 1.41×10^6 m^3 (4.98×10^7 ft^3) for the Mattaponi (USGS Station: 01674500; 1942-2007) and 2.66×10^6 m^3 (9.39×10^7 ft^3) for the Pamunkey (USGS Station: 01673000; 1972-2007) Rivers. The York River estuary also receives freshwater input from a large number of smaller ungaged subbasins and direct groundwater discharge to tidal waters. The York River system is classified as a microtidal, partially mixed estuary. Mean tidal range ranges from 0.7 m (2.3 ft) at its mouth to over 1 m (3.3 ft) in the upper tidal freshwater regions of the Mattaponi and Pamunkey Rivers (Sisson *et al.*, 1997). Principal bathymetric features of the York River consist of an axial channel flanked by broad, shallow shoals of less than 2 m (4.6 ft) in depth (Nichols *et al.*, 1991); main channel depths are on the order of 14 m (46 ft) near Gloucester Point to 6 m (20 ft) near West Point. Because the Mattaponi and Pamunkey Rivers do not exhibit a prominent fall-line as delineated by other major western shore Bay tributaries, the uppermost extent of tidal propagation is somewhat variable and on the order of 120 km (75 mi) upriver on the Mattaponi and as far as 150 km (93 mi) upriver on the Pamunkey (Lin and Kuo, 2001). Salinity distribution along the York River estuary ranges from tidal freshwater to polyhaline regimes.

Climate

Due to Virginia's varied landscape and close association with large water masses, the state's climate is diverse and can be classified into five different regions: the Tidewater, Piedmont, Northern Virginia, Western Mountain and Southwestern Mountain regions (www. Climate.Virginia.edu/description.htm). The York River watershed is located within the Tidewater and Piedmont climate regions. Climate within the York River basin is moderate with an average annual temperature of 14°C (57°F). Average winter season temperatures range from 2-5°C (36-41°F), with average daily minimum values of -5 to -1°C (23-30°F). Colder winter temperatures are associated with the more northwestern portions of the watershed. Average summer daily maximum temperatures vary from 23-24°C (73-75°F) with average daily maximum values ranging from 29-31°C (84-88°F). Warmer summer temperatures are associated with the lower, southern portions of the watershed.

Average annual precipitation rates within the watershed varies from 111 cm (44 in) in the upper reaches of tidal waters (Walkerton; 1932-2007) to 121 cm (48 in) in lower reaches (Williamsburg; 1948-2007). Precipitation is generally well distributed throughout the year. Much of this rainfall is associated with storms resulting from warm and cold frontal systems that generally track from west to east. In the vicinity of the Virginia coast, storm movement is typically northeastward paralleling the coast and Gulf Stream (www. Climate.Virginia.edu/description.htm). Excessive rainfall can result from hurricanes and tropical storms that cross Virginia. These large-scale events generally occur in early August and September. During September, anywhere from 10-40 percent of Virginia's rainfall comes from tropical cyclones. Average annual seasonal snowfall varies from approximately 51 cm (20 in) in the Piedmont region to less 18 than 25 cm (10 in) in the lower southern Coastal Plain regions (USDA County Soil Surveys). Average relative humidity in the mid-afternoon is on the order of 50 percent throughout the watershed.

Reserve Components

CBNERRVA consists of four components, Goodwin Islands, Catlett Islands, Taskinas Creek and Sweet Hall Marsh, which represent a diversity of coastal ecosystems found within the York River estuary and its principle tidal tributaries (Figure 3). The Goodwin Islands, located near the mouth of the York River, are a 148 ha (366 acres) archipelago of polyhaline salt-marsh islands surrounded by inter-tidal flats, extensive submerged aquatic vegetation (SAV) beds, and shallow open estuarine waters (Figure 4). The Catlett Islands, 220 ha (542 acres) in area, consist of multiple parallel ridges of forested wetland hammocks, forested upland hammocks, emergent mesohaline salt marshes and tidal creeks surrounded by shallow subtidal areas that once supported beds of submerged aquatic vegetation (Figure 5). Taskinas Creek encompasses 433 ha (1070 ac) within the boundaries of York River State Park (YRSP) (Figure 6). The non-tidal portion of Taskinas Creek contains feeder streams that drain oak-hickory forests, maple-gum-ash swamps and freshwater marshes which transition into tidal oligo and mesohaline salt marshes. Sweet Hall Marsh, 443 ha (1094 ac) in area, represents an extensive tidal fresh water-oligohaline marsh ecosystem located in the Pamunkey River, one of two major tributaries of the York River (Figure 7). Details regarding general location, ownership, management, physical conditions, representative habitats, rare and endangered flora and fauna, cultural/historical resources, and identified management issues are provided below for each Reserve component.

GOODWIN ISLANDS

Location

The Goodwin Islands (37° 13' N; 76° 23' W; Figure 4) component of the CBNERRVA is located on the southern side of the mouth of the York River. The islands are at the northeastern tip of York County approximately 10 km (6 mi) down the York River from VIMS.

Ownership and Management

Goodwin Islands are owned by the College of William and Mary. VIMS serves as the on-site manager of the islands and assures consistency with the MOU between VIMS/College of William and Mary and NOAA dated February 6, 1991.

Physical Conditions

Water circulation patterns around the islands are influenced by York River discharge and wind patterns of the Chesapeake Bay. Tides at the Goodwin Islands are semi-diurnal and display an average range of 0.7 m (2.3 ft). Mean seasonal water temperature values range from 13.7-15.6°C (56.7-60.1°F) for spring (March-May), 25.7-27.2°C (78.3-81.0°F) for summer (June-August), 18.0-19.2°C (64.4-66.6°F) for fall (September-November), and 4.7-8.2°C (40.5-46.8°F) for winter (January-February, and December). Located within the polyhaline region of the York River estuary, mean seasonal salinity values range from 13.9-23.0 psu for spring, 17.2-23.0 psu for summer, 16.5-24.0 for fall, and 15.9-23.3 psu for winter. Summary water quality statistics were derived from SWMP 15-minute interval data for the years 1998-2004.

Representative Coastal Habitats

Consisting of an archipelago of salt-marsh islands, the Goodwin Islands component core area is approximately 148

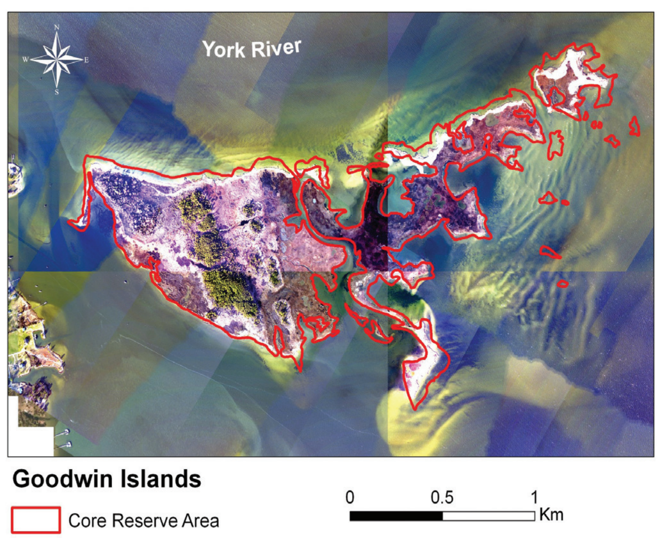

Figure 4. Aerial photo of Goodwin Islands Reserve component delineating core boundary.

ha (366 ac) in area. Primary ecological community groups occurring at Goodwin Islands include tidal meso-polyhaline marshes, maritime dune grasslands, salt scrub, and maritime upland forest (Erdle and Heffernan, 2005a). Salt marsh vegetation is dominated by smooth cordgrass (*Spartina alterniflora*) and saltgrass (*Distichlis spicata*). Other marsh associates include salt meadow hay (*Spartina patens*), glasswort (*Salicornia virginica*), sea-lavender (*Limonium carolinianum*), and stands of black needlerush (*Juncus roemerianus*). Characteristic species of the narrow stands of maritime dune grasslands include saltmeadow hay (*Spartina patens*), beach panic grass (*Panicum amarum*), seaside goldenrod (*Solidago sempervirens*) seaside spurge (*Chamaesyce polygonifolia*) and searocket (*Cakile edentula*). Salt shrubland community, consisting primarily of groundsel tree (*Baccharis halimifolia*) and saltbush (*Iva frutescens*), is irregularly scattered along low dunes and the island perimeter. The higher, interior western portions of the Goodwin Islands support a large stand of loblolly pine (*Pinus taeda*) with some mixed oak. The understory is dominated by southern wax myrtle (*Myrica cerifera*) and to a lesser degree red bay (*Persea palustris*). The northwestern corner of the island contains a fringe forest of sugarberry (*Celtis laevigata*), slippery elm (*Ulmus rubra*) and cottonwood (*Populus deltoides*); understory consists of Chinese privet (*Ligustrum obtusifolium*) and other shrub species. The surrounding aquatic zone includes extensive SAV beds of eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) approximately 183 ha (453 ac) in area (Orth *et al.*, 2005), large expanses of unvegetated bottoms, and shallow open estuarine waters.

Rare Plant and Animal Species

Flora and fauna surveys conducted to date do not indicate the presence of rare plant and animal species. Breeding bald eagles have been documented in recent years, although Tropical Cyclone Isabel damaged nesting habitat in the fall of 2003 (Watts, pers. comm., 2004).

Cultural and Historic Resources

An archaeological survey has not been conducted at Goodwin Islands. Based on observations and personal communications, Goodwin Islands contains prehistoric and historic resources.

Identified Management Issues

Identified resource management issues on Goodwin Islands and the immediate surrounding region include: (1) control of known problem invasive plant species which include common reed (*Phragmites australis*), japanese honeysuckle (*Lonicera japonica*), japanese stilt grass (*Microstegium vimineum*), and border privet (*Ligustrum obtusifolium*), (2) control of native animal problem species which include raccoon (*Procyon lotor*), fox species and white-tailed deer (*Odocoileus virginicus*), (3) assessment, protection and restoration of critical spawning, nesting and nursery habitat with specific emphasis on colonial nesting birds such as the great blue heron (*Ardea herodias*), horseshoe crab (*Limulus polyphemus*) spawning grounds, breeding and nesting areas for shorebirds including American oystercatchers (*Haematopus palliates*), and diamondback terrapins (*Malaclemys terrapin*), (4) assessment of sea level rise and shoreline erosion on critical habitats and geomorphic features, (5) restoration of SAV beds to past aerial coverage, (6) continued implementation of hunting management plan, (7) assessment of direct and indirect impacts of fishing activity on natural resources, (8) development of petroleum/toxic material spill contingency and response plans, (9) development of a fire contingency plan, (10) assessment of increased development and public access pressures on natural, cultural and historic resources, (11) survey of archaeological resources and development of a archaeological resource management plan, and (12) unauthorized public use of the Reserve which includes non-permitted collection of plants and animals, artifact collection, and unleashed domestic animals.

CATLETT ISLANDS

Location

The Catlett Islands (37° 18' N; 76° 33' W; Figure 5) are located approximately 18 km (11 mi) from the mouth of the York River and 8 km (5 mi) from VIMS, on the North side of the York River in Gloucester County, Virginia. Timberneck Creek flows into the York River on the eastern side of the Catlett Islands and Cedarbush Creek enters the river on the western side. Poplar Creek bisects the two large areas of the Catlett Islands.

Ownership and Management

The Reserve core encompasses the entire Catlett Island ecological unit except for a small portion (32 ha or 79 ac; Parcel ID: 88) located on the most northwest portion of the islands. The majority of land comprising the Catlett Islands component is owned by Timberneck LLC (Parcels 64, 87, 89, 90 and 91). Parcel size is 47 ha (115 ac) for tract 64, 63 ha (155 ac) for tract 87/89, and 45 ha each (112 ac) for tracts 90 and 91. VIMS/W&M holds deed to a small portion (20 ha; 48 ac) of the most southeast portion (Parcel 65) of the island complex. VIMS serves as the on-site manager of the Catlett Islands and assures consistency with the Catlett Island National Estuarine Research Reserve in Virginia Conservation Easements dated September 5, 1990 and November 14, 1990, and as amended in 2008.

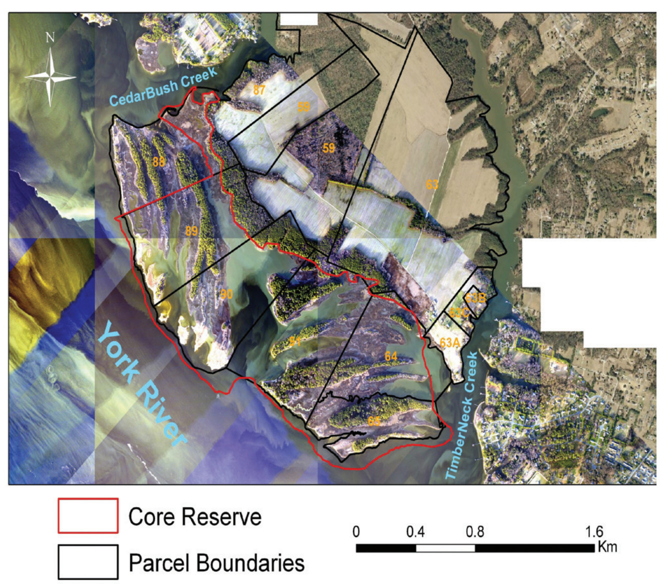

Figure 5. Aerial photo of Catlett Islands Reserve component delineating core boundary and tract parcels.

Physical Conditions

Tides at the Catlett Islands are semi-diurnal and display an average range of 0.8 m (2.6 ft). Mean seasonal water temperature values range from 15.2-18.7°C (59.4-65.7°F) for spring, 25.2-28.5°C (77.4-83.3°F) for summer, 14.9-20.9°C (58.8-69.6°F) for fall, and 4.5-12.1°C (40.1-53.8°F) for winter. Mean seasonal salinity values range from 10.7-22.6 psu for spring, 15.1-23.1 psu for summer, 13.2-25.2 psu for fall, and 10.3-23.1 psu for winter. Summary water quality statistics were derived from weekly interval data from the Alliance for the Chesapeake Bay for the years 1995-2004.

Representative Coastal Habitats

The Catlett Islands component, approximately 220 ha (542 ac) of core area, consists of multiple parallel ridges of forested hammocks and emergent wetlands. Primary ecological community groups occurring at Catlett Islands include tidal meso and polyhaline marshes, forested wetlands and maritime upland forests (Erdle and Heffernan, 2005b). Smooth cordgrass (*Spartina alterniflora*) prevails over much of the marsh area along with saltgrass (*Distichlis spicata*), saltmeadow hay (*Spartina patens*), black needlerush (*Juncus roemerianus*) and various halophytic forbs. Estuarine scrub/shrub vegetation including saltbush or high-watershrub (*Iva frutescens*), groundsel tree (*Baccharis halimifolia*), southern bayberry (*Myrica cerifera*) and northern bayberry (*Myrica pennsylvanica*) occurs in transitional areas from salt marsh to forested wetlands and hammock regions. Maritime upland forests, dominated by oak species (*Quercus phellos*, *Q. falcata*, *Q. pagoda*), loblolly pine (*Pinus taeda*) and to a lesser degree black cherry (*Prunus serotina*), red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*) and other tree species dominate the higher terrain.

Rare Plant and Animal Species

Flora surveys conducted to date do not indicate the presence of rare plant species. Bald eagles have been documented on Catlett Island in years past and currently continue to utilize the Island. While there has been no successful breeding activity in recent years (2004-2005), a nest was rebuilt in 2005 and breeding activity is currently being evaluated (Watts, pers. comm.).

Cultural and Historic Resources

A cultural resource overview has been conducted for the Timberneck Farm and adjacent Catlett Islands (Blanton *et al.*, 1993). The overview documented relatively few Archaic (10,000-2,500 yrs B.P.) sites, and on the order of ten each of Middle Woodland (2,500-1,000 yrs B.P.) and Late Woodland (1,000-400 yrs. B.P.) sites. With respect to historic sites, numerous site occupations from the seventeenth through twentieth centuries have been identified.

Identified Management Issues

Identified resource management issues on Catlett Islands and immediate surrounding region include: (1) control of known problem invasive plant species which include common reed (*Phragmites australis*), japanese honeysuckle (*Lonicera japonica*), and blunt-leaved privet (*Ligustrum obtusifolium*), (2) impact assessment and potential control of the southern pine bark beetle, (3) control of native animal problem species which include raccoon (*Procyon lotor*), fox species and whitetailed deer, (4) assessment, protection and restoration of critical colonial bird nesting habitat with specific emphasis on the great blue heron (*Ardea herodias*), (5) assessment, protection and restoration of critical breeding and nesting areas for shorebirds including American oystercatchers (*Haematopus palliates*), (6) assessment of sea level rise and shoreline erosion on critical habitats and geomorphic features, (7) development and implementation of a hunting management plan, (8) development of a petroleum/toxic material spill contingency and response plans, (9) development of a fire contingency plan, (10) assessment of increased development and public access pressures on natural resources, (11) source tracking of tidal creek fecal coliform contamination and development of remediation strategies, (12) determination of water quality status for surrounding waters and assess the potential for SAV and oyster restoration, (13) enhanced survey of archaeological resources and development of a archaeological resource management plan, and (14) unauthorized public use of the Reserve which includes non-permitted collection of plants and animals, artifact collection, hunting and camping.

TASKINAS CREEK

Location

The Taskinas Creek component (37° 24' N; 76° 42' W; Figure 6) is located within the boundaries of YRSP near the town of Croaker, in James City County, Virginia. The small subestu-

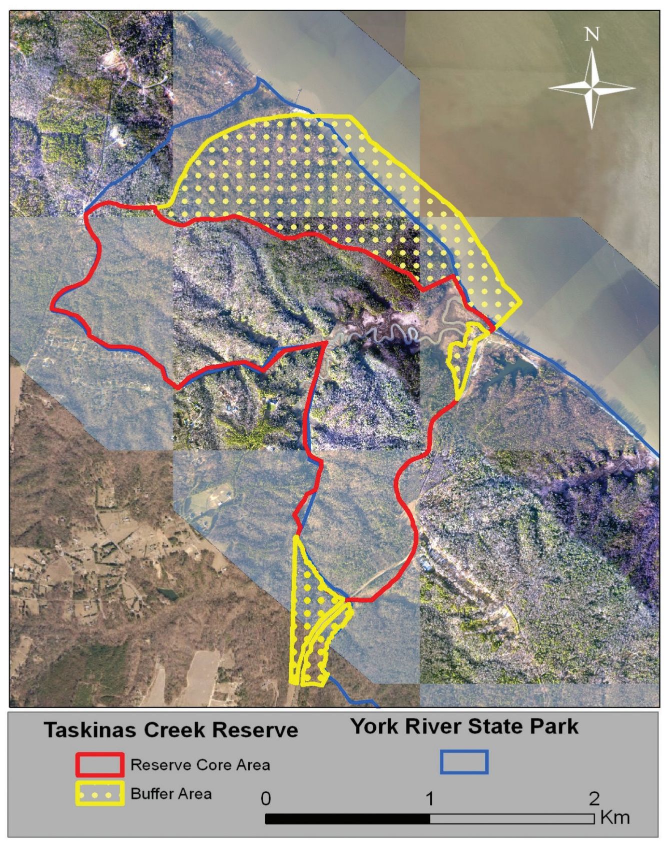

Figure 6. Aerial photo of Taskinas Creek Reserve component delineating core and buffer areas and YRSP boundary.

ary of the York River is located on the southern side of the river, approximately 28 km (17 mi) upriver from VIMS and 38 km (24 mi) from the mouth of the York River.

Ownership and Management

YRSP contains 1034 ha (2554 ac). All lands within the boundaries of YRSP are owned by the Commonwealth of Virginia. Lands within the Taskinas Creek Reserve component of YRSP, identified as the Taskinas Creek Management Unit in the YRSP Resource Management Plan (VaDCR 2000), are co-managed by the Virginia Department of Conservation and Recreation (VaDCR) and VIMS in a manner consistent with the MOU between VIMS/W&M and the VaDCR dated August 19, 2008.

Physical Conditions

Taskinas Creek water quality is influenced to a large degree by watershed drainage at low tide and mainstem York River during high tide conditions. Tides are semidiurnal and display an average range of 1.0 m (3.3 ft). Mean seasonal water temperature values range from 15.2-19.0°C (59.4-66.2°F) for spring, 26.8- 28.2°C (80.2-82.8°F) for summer, 15.7-18.3°C (60.3-64.9°F) for fall, and 3.6-9.0°C (38.5-48.2°F) for winter. Located within the mesopolyhaline region of the York River estuary, mean seasonal salinity values range from 4.0-14.0 psu for spring, 7.0- 18.2 psu for summer, 6.9-17.0 for fall, and 5.8-15.3 psu for winter. Summary water quality statistics were derived from SWMP 15-minute interval data for the years 1998-2004.

Representative Coastal Habitats

The Taskinas Creek component consists of a 285 ha (704 ac) core and 148 ha (366 ac) buffer region within the boundaries of YRSP (Figure 6). The upper, most inland boundary of the core area coincides with the 30.5 m (100 ft) contour and the seaward boundary of the core and buffer is defined by the 0.3 m (1 ft) water depth contour which delineates the seaward limit of the intertidal zone. The non-tidal portion of Taskinas Creek contains feeder streams that drain oak-hickory forests, maple-gum-ash swamps and freshwater marshes. Freshwater mixed wetlands are found in the upstream reaches of Taskinas Creek. Three-square (*Scirpus americanus* and *S. olneyi*) and big cordgrass (*Spartina cynosuroides*) characterize the middle marsh reaches. Salt marsh vegetation dominated by smooth cordgrass (*Spartina alterniflora*) is found in the lower reaches of the creek, near the outlet to the York River.

Rare Plant and Animal Species

A population of mountain camellia (*Stewartia ovata)* (G4/S2), first discovered in 1990, was rediscovered at the Reserve in 2006. Thirty two plants were located in six subpopulation areas (Meyers *et al*., 2008a). One bald eagle nesting location is known just outside the boundary of YRSP and the Taskinas Creek Reserve. Eagles use both the water and upland resources within the Reserve boundary for fishing and nesting.

Cultural and Historic Resources

Archaeological studies have been conducted within YRSP. Two sites of interest have been dated to between 1000 B.C. to 1500 A.D. (Egloff, 1988). Of significance is a previously undefined type of ceramic ware (Croaker Landing) and type of projectile point (Potts Side- Notched). Additional information and archaeological/historical sites and areas of archaeological resource potential within YRSP are provided in the YRSP Resource Management Plan (VaDCR 2000).

Identified Management Issues

Identified resource management issues for the Taskinas Creek component of the Reserve and its immediate surrounding region include: (1) control of known problem invasive plant species which include the common reed (*Phragmites australis*), (2) assessment of sea level rise and shoreline erosion on critical habitats and geomorphic features, (3) source tracking of tidal creek fecal coliform contamination and development of remediation strategies, (4) assessment of increased development and public access pressures on natural resources, (5) enhanced survey of archaeological resources and development of an archaeological resource management plan, (6) determination of Reserve and YRSP carrying capacity to accommodate public use, research and education, (7) assessment of foot, bike and horse traffic on trail system, and (8) unauthorized public use of the Reserve which includes non-permitted collection of plants, animals and artifacts.

SWEET HALL MARSH

Location

Sweet Hall Marsh (37° 34' N; 76° 50' W; Figure 7) is located in the tidal freshwater-oligohaline transitional zone of the Pamunkey River, one of two major tributaries of the York River. Historically, Sweet Hall Marsh has represented the lower-most extensive tidal fresh water marsh located in this riverine system. Sweet Hall Marsh is approximately 23 km (14 mi) from West Point, where the Pamunkey and Mattaponi converge to form the York River. The site is 65 km (40 mi) upriver from VIMS and 75 km (47 mi) from the mouth of the York River.

Ownership and Management

Sweet Hall Marsh is privately owned by the Tacoma Hunting and Fishing Club. Parcel size is 384 ha (949 ac) for tract 18 and 59 ha (145 ac) for the buffer tract 17. VIMS serves as the onsite manager of the Sweet Hall Marsh component of the Reserve and assures consistency with the Sweet Hall National Estuarine Research Reserve in Virginia Management Agreement dated May 1, 2008.

Physical Conditions

Tides at Sweet Hall Marsh are semi-diurnal and display an average range of 1.0 m (3.3 ft). Mean seasonal water temperature values range from 14.7-16.7°C (58.5-62.1°F) for spring, 26.7-27.9°C (80.1-82.2°F) for summer, 18.6-19.1°C (65.5-66.4°F) for fall, and 4.7-6.3°C (40.5-43.3°F) for winter. Located within the oligohaline, lower freshwater reaches of the Pamunkey River, mean seasonal salinity values range from 0.1-3.4 psu for spring, 0.1-8.4 psu for summer, 0.3-8.4 psu for fall, and 0.1-3.2 psu for winter. Summary water quality statistics were derived from SWMP 15-minute interval data for the years 2002-2004.

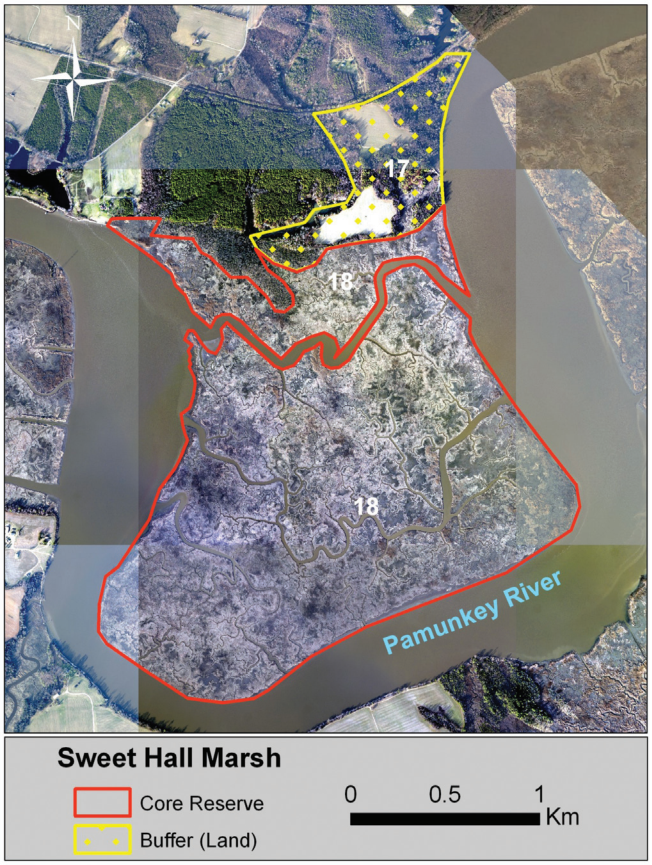

Figure 7. Aerial photo of Sweet Hall Marsh Reserve component delineating core and buffer boundaries.

Representative Coastal Habitats

The Sweet Hall Marsh component consists of a 384 ha (949 ac) core region that encompasses emergent, fresh and low salinity marsh, seasonally flooded forested wetlands and scrub-shrub wetlands. A 59 ha (145 ac) buffer consists primarily of uplands forests and open agricultural fields. The emergent marsh community is classified as freshwater mixed and includes arrow arum (*Peltandra virginica*), big cordgrass (*Spartina cynosuroides*), smartweeds (*Polygonum spp.*) species, rice cutgrass (*Leersia oryzoides*), wild rice (*Zizania aquatica*), sedges (Carex spp.) and rushes (*Scirpus* spp.), cattail (*Typha* spp.) and panic grass (*Panicum virgatum*). The dominant canopy species in the flooded forested wetlands include green ash (*Fraxinus pennsylvanica*), black gum (*Nyssa sylvatica*), red maple (*Acer rubrum*) and ironwood (*Carpinus caroliniana*). Scrub-shrub species include wax myrtle (*Myrica cerifera L.*), mountain laurel (*Kalmia latifolia*) and arrow wood viburnum (*Viburnum dentatum*). The uplands in the buffer zone consist of agricultural fields and mixed hardwoods and pine.

Rare Plant and Animal Species

The sensitive joint vetch (*Aeschenomene virginica*), a candidate for federal listing as an endangered species, has historically been found at Sweet Hall Marsh but has not been found in recent surveys. Fauna surveys conducted to date have found the butterfly species *Problema bulenta*, a "Rare Skipper" species that has both a global and state rare ranking (Myers *et al.*, 2008b). Several bald eagles nesting locations are located near, but not within the boundaries of Sweet Hall Marsh. Eagles use both the water and upland resources within the Reserve boundary for fishing and resting.

Cultural and Historic Resources

Sweet Hall Marsh has not been surveyed for archaeological resources. Due to its long history of human use, it is expected that Sweet Hall Marsh and adjacent uplands would yield significant prehistoric and historic resources.

Identified Management Issues

Identified resource management issues at Sweet Hall Marsh and immediate surrounding region include: (1) assessment and control of problem invasive plant species which may include the non-native common reed (*Phragmites australis*), (2) assessment of relative sea level rise impacts (includes subsidence due to ground water withdrawal and other factors) on plant communities, (3) assessment of long-term reductions in stream flow on salinity patterns and the impacts on plant communities and fish spawning grounds, (4) source identification of mercury inputs and impacts upon upriver ecosystems, (5) assessment of introduced Blue catfish populations and impact on local fish populations (6) assessment of increased development and public access pressures on natural resources, and (7) survey of archaeological resources and development of archaeological resource management plan.

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York River Geology

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ABSTRACT

The four separate sites of the Chesapeake Bay National Estuarine Research Reserve in Virginia are within the Coastal Plain province of the mid-Atlantic. The surficial geology at each site is of Quaternary age, primarily Holocene wetlands. The site at Taskinas Creek is set into Tertiary age strata. The underlying strata increase in age up-stream. Regionally, the Late Tertiary and Quaternary geology is a function of the series of major transgressions and regressions, during which the successively more recent high stands of sea level generally have not reached the level of the preceding high stand. As a consequence, stratigraphically higher, younger deposits occur topographically below exposures of the older strata. The two down-stream reserve sites are within the area of the Eocene age Chesapeake Bay Impact Crater. Also at these two sites, the tidal marshes are superimposed on a ridge and swale topography. The local rate of sea-level rise, approximately 4 mm/yr, is the underlying process driving changes to the tidal marshes at all four sites. The Goodwin Islands, at the mouth of the York River with exposure to Chesapeake Bay, can be severely impacted by storm waves and surge. Future research should include a program ofcoring to develop the time-history of recent rise of sea level and assist on-going efforts toward mapping the regional geology and toward understanding the local and regional ground-water systems.In addition, establishment of permanent benchmarks to document elevation would enable long-term monitoring of subsidence and facilitate differentiation of the eustatic and isostatic components of changes in relative sea-level rise relative to climate change or other factors.

INTRODUCTION

All four separate sites of Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) are within the Coastal Plain province of the mid-Atlantic along the York River and its tributaries. The surficial geology at each of the locations is of Quaternary age, primarily Holocene wetlands that formed within the past few thousand years. The underlying strata increase in age up-stream. Additionally, the two down-stream reserve sites, Goodwin and Catlett Islands, are within the area of the approximately 35 million year old Chesapeake Bay Impact Crater.

THE CHESAPEAKE BAY IMPACT CRATER

During the Eocene Epoch, approximately 35.5 million years ago (Koeberl *et al.*, 1996), a comet or meteor struck the earth at what today is the southern part of Chesapeake Bay (Figure 1). At that time, sea level was a hundred or so meters higher than today. Chesapeake Bay did not exist, and the area hit by the bolide was a continental shelf, marine environment. Poag (1996) characterizes the resulting crater as "the seventh largest impact crater on Earth." The roughly circular crater is approximately 90 km (56 miles) in diameter and nearly 2 km (1.2 miles) deep (Powars and Bruce, 1999, among others.) According to Poag *et al*. (1994), the crater was filled extremely rapidly with a breccia, composed of clasts of the disrupted strata. Poag *et al*. (1994) named the fill deposit the Exmore breccia and consider it to be an impact tsunami deposit.

The excavation cut strata down through the Lower Cretaceous and into the Paleozoic basement rocks. As several of the strata are aquifers, the crater and its fill disrupt the regional, deep ground-water-system. Water presently flowing in the aquifers flows around the crater while the crater itself is "a single huge reservoir ... (in which) pore spaces are filled with briny water that is 1.5 times saltier than normal seawater" (USGS, 1998).

Probably because of its rapid deposition, the Exmore breccia compacted more rapidly than the surrounding, older, strata with the result that its upper surface has dropped or sagged through time. Poag *et al*. (1999) state that "the crater is buried under 300-1,000 m of post impact late Eocene to Quaternary sedimentary strata." The overlying, post-impact strata thicken slightly in the area over the crater as shown by Powars and Bruce (1999), among others, as the sediments attempted to fill the shallow basin, with the consequence that there is differential compaction between the slightly thicker strata over the crater and the surrounding sediments. The compaction likely was the cause of the apparent tectonic activity that, ac-

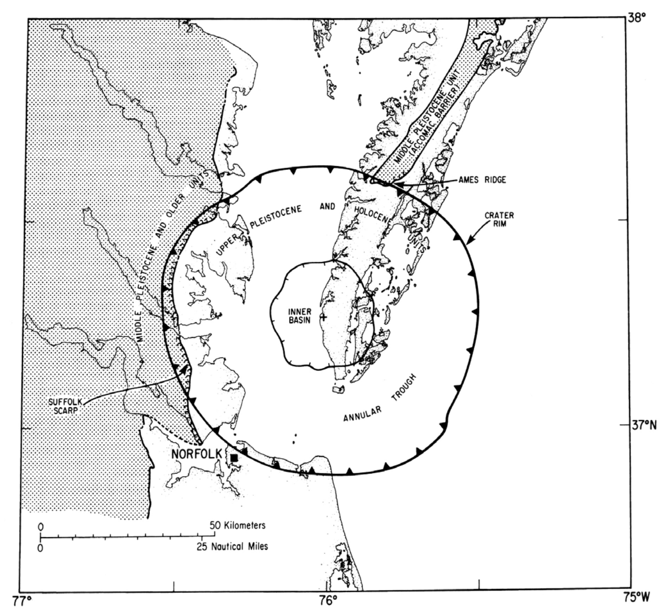


Figure 1. Map depicting the extent of the Chesapeake Bay Impact Crater (Figure 23 from Poag *et al.*, 1994).

cording to Ramsey (1992), writing before the recent series of crater-related studies, effectively ended by Bacons Castle time. However, the presence of small, near surface growth-faults suggests that the process might continue today and be the cause of the small earthquakes associated with the outer rim of the crater (Johnson *et al.*; 1998). The Catlett Islands essentially sit above the crater rim, near the small faults observed by Johnson *et al*. (1998).

REGIONAL LATE TERTIARY AND QUATERNARY GEOLOGY

The later Tertiary and Quaternary strata of the Coastal Plain result from deposition in shallow marine or estuarine environments accumulated during a series of marine transgressions. Substantial, hundred meter scale, variations in sea level were caused by climate driven changes in the volume of the ice caps. As sea level rose, the surf-zone moved across and eroded the gently sloping land surface. When sea level was nearly static, the erosion of the shoreline and near shore zone sculpted a distinct steeper slope. The eroded sediments along with material supplied by river input were deposited somewhat further offshore. As it happened, each successively younger, sea-level high stand was somewhat lower than its predecessor. This probably occurred as a result of several factors including a long-term decrease in global average temperature beginning in the Cretaceous and an increase in ocean basin volume that accompanied the growth of the Atlantic. Hobbs (2004) reviews the regional correlation of strata and history of the stratigraphic nomenclature.

The deposition of thin, roughly tabular beds followed by a regression and subsequent transgression has resulted in the stair-step geological framework of the mid-Atlantic Coastal Plain (Figure 2). The upper Pliocene and Pleistocene strata rest upon older Tertiary strata that outcrop in valley walls cut into the inland portion of the coastal plain. Because the younger units were formed by the erosion and redeposition of the older units and because of a paucity of fossils in many strata, identification of specific formations often is difficult requiring, in addition to an understanding of the regional stratigraphic setting, local experience and knowledge of elevation. Most formations are separated by unconformities. The older Tertiary units have a better preserved fauna, listed by Ward (1985) who also provides descriptions of the older strata of the Pamunkey River area. Most of the Pleistocene stratigraphic section is weakly cemented and poorly indurated. As a consequence, when exposed in steep faces, the sediments are easily eroded.Ward and Blackwelder (1980) named the Eastover Formation in their revised interpretation and nomenclature for the Upper Miocene and Lower Miocene strata. Johnson and Berquist (1989) indicated that the lower Eastover contains few fossils though there are fairly abundant ghosts and molds. The upper Eastover is fossiliferous and is separated from the overlying Yorktown Formation by an unconformity. In areas where fossils and other identifying features are absent, it is difficult to distinguish between the Eastover and the Yorktown.

Across the outer coastal plain, the Pliocene age Yorktown Formation is widespread and easily identifiable strata. Krantz (1990, 1991) places its age as between 4.8 million and 2.8 million years fefore present. According to Cronin *et al*. (1984) it was deposited during three transgressive episodes. The depositional environment was shallow marine: inner shelf, barrier island, estuarine, lagoon. Ward and Blackwelder (1980), Johnson and Ramsey (1987), and Johnson and Berquist (1989) suggest that the fossils indicate a subtropical setting for the upper portion of the formation. The Yorktown is widespread, occurring from Maryland to North Carolina.

According to Johnson and Peebles (1985) and Ramsey (1987) the Yorktown and Eastover formations are cut by an angular unconformity; thus the Bacons Castle Formation, named by Coch (1965), sits disconformably atop the Yorktown. Ramsey (1987, 1988) subdivided the Bacons Castle into tidal flat deposits (Barhamsville member) and fluvial and estuarine gravel and sand (Varina Grove member). In some areas, Bacons Castle sediments fill channels that were cut into underlying deposits. The formation contains a wide variety of sediments and sedimentary structures but is lacking in usable fossils or other dateable materials. Primarily because of its stratigraphic position, the Bacons Castle Formation has been assigned to the Late Pliocene.

Oaks and Coch (1973) used the Moorings unit for an informal stratigraphic unit west of the Surry Scarp. Johnson and Berquist (1989) characterized the Moorings unit as having an eastern sand facies and a western clay facies; both of which usually are less than 3 m thick. They described the clay fa-

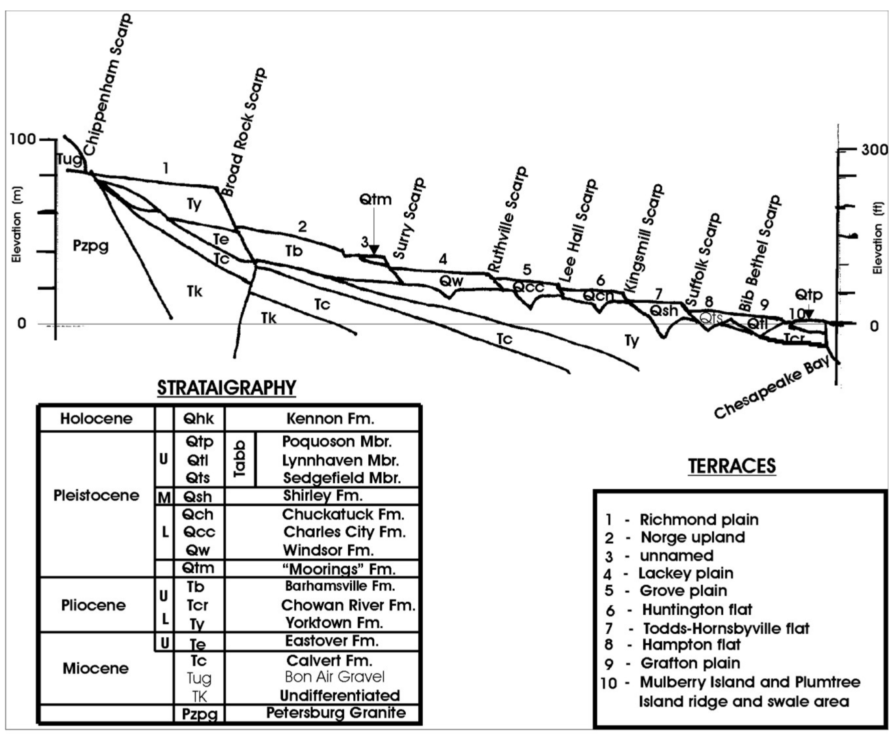


Figure 2. A schematic cross section of geologic framework of the York River area of the mid-Atlantic Coastal Plain (after Johnson and Hobbs, 1990; and Hobbs, 2004).

cies as commonly bioturbated, massively bedded, silty clay to muddy sands. The sand facies is massively bedded find sand generally lacking sedimentary structures except for local clay laminations and drapes. According to Johnson and Berquist (1989), "the Moorings unit formed as a barrier-beach (sand facies) and back barrier lagoon or bay (clay facies) couplet. The sand (barrier-beach) facies, which lies to the east of the clay facies, is at slightly higher elevations and grades laterally into the fine-grained sediments at lower elevations." This is exactly as would be expected with the barrier beach seaward, east, of and topographically above the bay or lagoon. By virtue of being stratigraphically above the Windsor Formation and below the Bacons Castle and being west of the Surry Scarp, Johnson and Berquist (1989) place the Moorings unit in the Late Pliocene or Early Pleistocene.

The Windsor Formation rests uncomfortably atop the Yorktown and immediately seaward of the Surry Scarp. As reviewed in Hobbs (2004), the Surry Scarp clearly crosses North Carolina and Virginia and has been mapped as far south as Florida. The terrace below the Surry Scarp is the Lackey Plain (Johnson, 1972) and is upper surface of the Windsor. According to Johnson and Berquist (1989) no diagnostic fossils have been described from the Windsor. They also describe the sedimentary sequence as fining upward from coarse, fluvial sediments to bioturbated, massively bedded, muddy sands and sandy muds of estuarine origin. Mostly because of its stratigraphic position, the Windsor Formation generally is considered to date from the early Pleistocene.

The Charles City Formation (Johnson and Berquist, 1989) sits below the Ruthville Scarp which separates the Lackey Plain from the younger Grove Plain. The Ruthville Scarp (Johnson and Berquist, 1989) was cut during deposition of the Charles City Formation They describe its sediments as fining upward gravelly sands to silty to clayey sands with very coarse sediments, pebbles, cobbles, and boulders, at the basal contact. They describe the Charles City Formation as being severely eroded and preserved only as isolated sections which often outcrop in stream banks and terraces. According to Johnson and Ward (1990), datable fossils have yet to be found in the Charles City. Based on its stratigraphic position beneath the Middle Pleistocene Chuckatuck and Shirley Formations, Johnson and Berquist (1989) place the Charles City Formation in the Early Pleistocene.

The Lee Hall Scarp (Johnson, 1972) has just over 4 m (12 ft) of relief above its toe at about 17 m (58 ft). It has a shallow rise and has been sufficiently cut by erosion in some areas as to be unrecognizable. It separates the Grove and Grafton Plains. The Chuckatuck Formation (Johnson and Peebles, 1985, 1987; Johnson and Berquist, 1989) underlies the Grafton Plain. According to Johnson and Berquist (1989) relative sea level reached about 19 m (60 ft) above present during Chuckatuck time. As with the other Pleistocene sedimentary units, the Chuckatuck Formation was formed from sediments eroded from older strata and has not yielded any age-definitive fossils or fossil assemblages. Johnson and Berquist (1989) state, "The lowermost beds for the Chuckatuck occupy channels cut at least 25 feet deep into older Pleistocene and Tertiary Sediments. The channel deposits commonly contain poorly sorted, basal pebbly-to cobbly-sand that is less than 6 inches thick." Because it is separated from the overlying Late Middle Pleistocene Shirley Formation by an unconformity, the Chuckatuck Formation likely is of Middle Pleistocene age.

Along the York River, the Camp Peary Scarp (Johnson, 1972) separates the Grafton Plain from the Huntington Flat which is the upper surface of the Shirley Formation (Johnson and Berquist, 1989). According to Johnson and Berquist (1989) the Shirley Formation contains fluvial, estuarine, marsh, shallow marine, and similar deposits. Based on dates (Mixon *et al.*, 1982 and Cronin *et al.*, 1984) of correlative deposits along the Rappahannock River, Johnson and Berquist (1989) indicate that the Shirley Formation has a Late Middle Pleistocene age of about 185,000 year (late in Oxygen Isotope Stage 7). The Shirley varies in thickness from a thin, feather edge at the Kingsmill Scarp, a Camp Peary correlative (Hobbs, 2004) to more than 16 m in paleochannels cut into the Eastover and older strata (Johnson and Berquist (1989).

The Suffolk Scarp (Figures 1 and 2) has been mapped for about 200 miles (300 km). Johnson (1972) considered it the most prominent scarp on the York James peninsula with 10 m (30 ft) of rise as it separates the Grafton Plain from the Hornsbyville Flat and correlatives. These plains are the surface of the Sedgefield Member of the Tabb Formation (Johnson, 1976, Johnson and Berquist, 1989). The Big Bethel Scarp marks the lower edge of the Hornsbyville Flat and the upper limit of the Hampton Flat. The Mulberry Island Flat is lower than the Hampton but the two are not separated by a well defined scarp. The Hampton and Mulberry Island Flats likely are the surface expression of the Lynnhaven and Poquoson Members of the Tabb Formation and were deposited during the last above present stand of sea level, on the order of 100,000 years ago, Oxygen Isotope Stage 5. Indeed each of the three members might represent one of the mini high stands during Stage (Toscano, 1992; Toscano and York, 1992). Holocene sediments, primarily marsh or swamp, colluvium, and alluvium, unconformably overlie older strata. The modern sediments occur filling and fringing flooded channels and at the foot of steep slopes.

The underlying process driving changes today, as it has been in the past, to the surficial geology is sea-level rise. According to the NOAA (2008) using data from a now discontinued tide gage at Gloucester Point, the average rate of sea-level rise from 1950 through 1999 at Gloucester Point was 3.95 mm/yr (1.3 ft/century). A longer record, 1929-1999, at Sewells Point in Hampton Roads, about 40 km (25 miles) to the south, yields a rate of 4.42 mm/yr (1.45 ft/century) (NOAA website, 2008). On areas with a shallow slope, sea-level rise causes a transgression of the water over the land, moving the shoreline landward. If the rate is not too great, sea-level rise also encourages the upward and, perhaps, outward growth of marshes in areas otherwise conducive to marsh growth. This progradation opposes the simultaneous marine transgression.

GEOLOGIC SETTING OF THE RESEARCH RESERVE SITES

Goodwin Islands

Johnson (1972) mapped the Pleistocene outcrops on the Goodwin Islands (Figure 3) as the Norfolk Formation, an earlier term for the Tabb Formation (Johnson and Berquist, 1989). He described the ridges as being "composed of fine to medium sand, with less than 10 percent silt and clay. Small quantities of gravelly sand occur locally on the ridges. On the broader ridges sediments are slightly finer on the west side of

Figure 3. An oblique, aerial photograph of the Goodwin Islands (from CBNERRVA).

the ridges. The sand on the crest of the ridge lacks distinctive primary sedimentary structures and shows shallow weathering profiles." According to Johnson (1972) there is a possibility that the lowest ridges were formed by progradation accompanying the most recent rise of sea level. The ridges on the Goodwin Islands are part of the Plum Tree Island Ridge and Swale Area (Johnson, 1972). The surficial deposits are relatively thin, perhaps indicating deposition during a relatively short and shallow submergence. Figure 4 is a geological map of the area. As a consequence of their low elevation and open exposure both to Chesapeake Bay, Mobjack Bay, and somewhat west along the York River, the Goodwin Islands are severely impacted by storm tides and waves.

Catlett Islands

The geology of the Catlett Islands (Figures 4 and 5) is similar to that of the Goodwin Islands. The islands themselves are

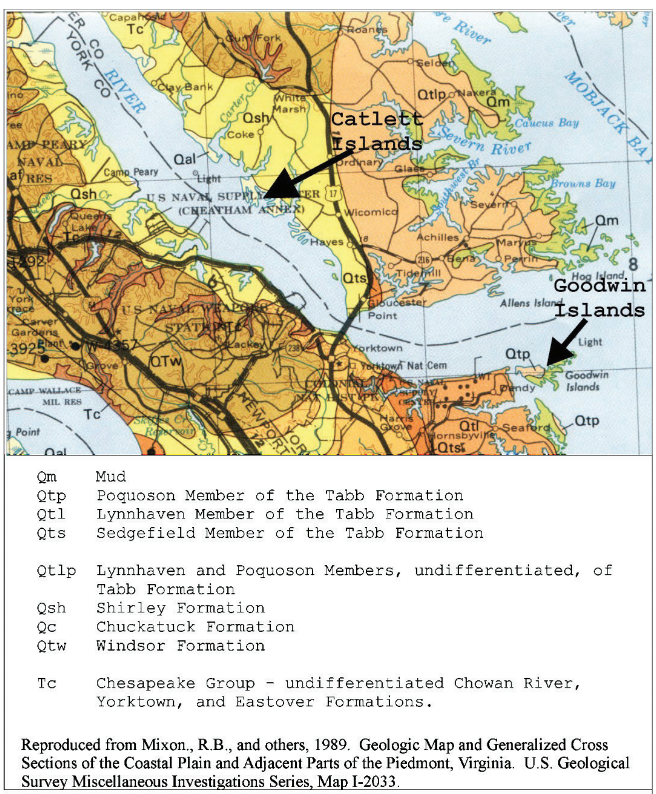


Figure 4. Geologic map depicting the Goodwin Islands and the Catlett Islands reserve site (from Mixon and others 1989).

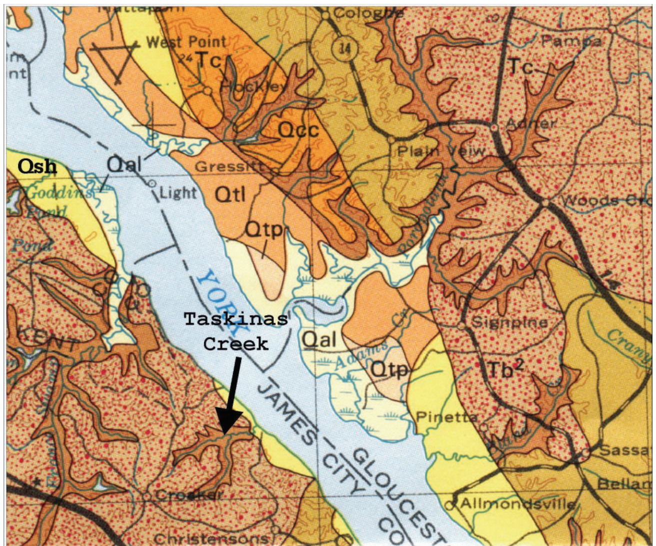
Figure 5. An oblique, aerial photograph of the Catlett Islands (from CBNERRVA).

the surface expression of low ridges comprised of Late Pleistocene deposits of the Tabb Formation (Mixon *et al.*, 1989). The primary differences are that the Catlett Islands are in a much more protected setting, on the north bank of the York River and that they abut a relatively steep river bank in which older strata (Shirley Formation) are exposed. Holocene marshes are growing on the fringes of the ridges. The islands are subject to innundation during storm tides, however the shelter provided by the adjacent mainland protects them from north, northeast, and east winds and, thus, also from many waves. The long fetch up the York River allows for substantial wave action along the Catlett Islands with the northwest winds that accompany some cold front and often occur with the passage of storms.

Taskinas Creek/York River State Park

The Taskinas Creek estuarine reserve site (Figure 6) has a much different setting that the other Reserve sites in the system. It is a small stream and tidal marsh system cut into the older sediments of the south bank of the York River. The 397 ha (980 acres) of the Reserve are within York River State Park and contain both tidal and non-tidal elements. The geology of the Taskinas Creek site (Figure 7) consists of modern swamp deposits, the Pleistocene deposits over which they are deposited, and older Tertiary strata into which the stream valley is cut. Although the geologic map does not differentiate the components of the Chesapeake Group, it most probably is

Figure 6. An oblique, aerial photograph of Taskinas Creek (from CB-NERR-VA).



Qal Alluvium
Qtp Poquoson Member of the Tabb Formation
Qtl Lynnhaven Member of the Tabb Formation
Qsh Shirley Formation
Qcc Charles City Formation

Tb² Bacon Castle Formation ("estuarine" facies)
Tc Chesapeake Group - undifferentiated Chowan River, Yorktown, and Eastover Fromations

Reproduced from Mixon., R.B., and others, 1989. Geologic Map and Generalized Cross Sections of the Coastal Plain and Adjacent Parts of the Piedmont, Virginia. U.S. Geological Survey Miscellaneous Investigations Series, Map I-2033.

Figure 7. Geologic map depicting the Taskinas Creek reserve site (from Mixon *et. al.*, 1989).

Figure 8. An oblique, aerial photograph of Sweet Hall Marsh (from CBNERRVA).

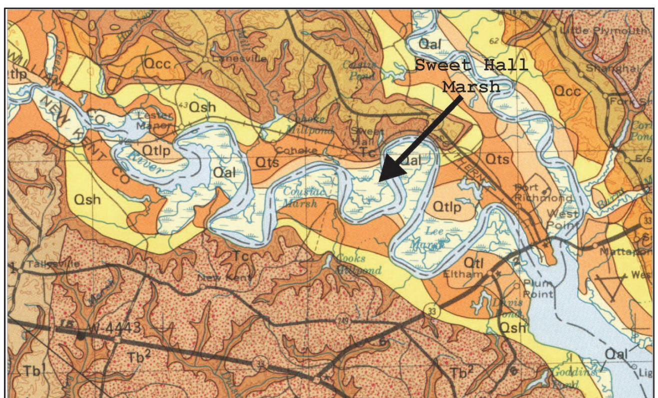
the Yorktown Formation exposed in the banks as the Bacons Castle Formation never is found below 60 ft in the vicinity of York River State Park (C.R. Berquist, Jr., pers. comm. 2005) and the site is north of any mapped occurrences of the Chowan River Formation.

Sweet Hall Marsh

Sweet Hall Marsh is the lower-most extensive tidal fresh water marsh located in the Pamunkey River, The marsh is the area bounded a tight meander of the Pamunkey and the adjacent upland (Figure 8). A small marsh creek runs across the base of the marsh separating much of it from the mainland. The marsh itself is a modern deposit sitting atop older strata (Figure 9). Outcrops of the Late Pleistocene Tabb Formation abut the marsh (Mixon *et al.*, 1989). Depths in the creek reach 4 m (12 to 13 ft)(NOS, 1980) whereas depths in the main channel reach 17 m (56 ft) and commonly run in excess of 7 m (22 ft). These perhaps surprisingly great depths might indicate that the river remains in a channel that was excavated during a low stand of sea level. Thus the channel is cut into older, more indurated sediments. The Pamunkey River's average annual discharge rate from 1972 to 2006 recorded at Hanover was 1,085 ft^3/s (USGS, 2005). The river's record peak flow was 40,300 ft^3/s which occurred with Hurricane Camille in August 1969. The second highest flow was 29,900 ft^3/s accompanied Hurricane Agnes in June 1972 (USGS, 2005). Although the river is unlikely to erode a comparably deep, new channel, it is possible that the cut-off creek might widen sufficiently to capture a larger portion of the river flow. Sweet Hall Marsh is near the center of an area of relatively rapid subsidence. Holdahl and Morrison (1974) calculated that region traversed by the lower portions of the Pamunkey and Mattaponi Rivers was sinking at a rate of 3.2 mm/yr (1.05 ft/century). By comparison, the same study depicted subsidence rates of nearly 3.0 mm/yr (0.98 ft/century) at Taskinas Creek and just under 2.8 mm/yr (0.92 ft/century) at the Goodwin Islands.

SUMMARY AND CONCLUSIONS

All four sites of the Chesapeake Bay National Estuarine Research Reserve in Virginia are within the Coastal Plain geological province. Regionally, the Late Tertiary and Quaternary geology has been controlled by the series of major marine transgressions and regressions, in which successively



Qal Alluvium
Qtl Lynnhaven Member of the Tabb Formation
Qts Sedgefield Member of the Tabb Formation

Qtlp Lynnhaven and Poquoson Members, undifferentiated, of Tabb Formation
Qsh Shorley Formation
Qcc Charles City Formation

Tb¹ Bacons Castle Formation ("fluvial" facies)
Tb² Bacons Castle Formation ("estuarine" facies)

Tc Chesapeake Group - undifferentiated Chowan River, Yorktown, and Eastover Formations.

Reproduced from Mixon., R.B., Et al., 1989. Geologic map and generalized cross sections of the coastal plain and adjacent parts of the piedmont, Virginia. U.S. Geological Survey Miscellaneous Investigations Series, Map I-2033.

Figure 9. Geologic map depicting the Sweet Hall Marsh reserve site (from Mixon *et al.*, 1989).

more recent high stands of the sea have not reached the level of the preceding high stand. As a result, while stratigraphically above older units, younger beds may be physically lower. Except where filling channels cut into the underlying strata, the formations tend to be tabular and nearly horizontal. Because younger beds are comprised of sediments eroded and reworked from older, it often is difficult to distinguish one from the other without knowledge of elevation. Several of the formations lack fossils or other time specific characteristics; thus assignment of geologic age is dependent upon other factors. Earlier researchers have inferred age based on relative stratigraphic age. More recently, researchers have attempted to fit the stratigraphy to the continually improving model of gross sea-level change, e.g. oxygen isotope stages.

The Catlett and Goodwin Islands reserve sites consist of modern marshes growing a Late Pleistocene substrate. Sweet Hall Marsh occupies the area inside a tight meander of the Pamunkey River and is adjacent to Late Pleistocene outcrops, thought the specific strata beneath the marsh are not known. The Taskinas Creek site is the valley of a small tributary of the York River. It too consists of Holocene marshes and late Pleistocene strata but also includes exposures of the older formations into which the valley is cut. The two downstream Reserve sites, the Catlett Islands and Goodwin Islands, lie above the thirty five million year old Chesapeake Bay Impact Crater. Author's Note: substantial portions of this report are rewritten from Hobbs (2004), Johnson and Berquist (1989), and an unpublished contract report.

RESEARCH NEEDS

There are several avenues of geological research that should be advanced in the Research Reserve sites and adjacent areas of the York River system. There should be a coordinated program of coring through the marshes in the four sites in order to date the basal peats and develop the time-history of the recent rise of sea level. Comparing the differences between sites would provide information concerning relative rates of subsidence (or uplift) during the past several thousand years over the entire reserve system. Differentials in the local tectonic changes might result from different underlying conditions as a result of the Chesapeake Bay Impact Crater. Additionally, there are regional questions concerning potential high-stands of sea level through the past few thousand years. The ridge-and-swale geography of parts of the Goodwin and Catlett Islands suggests that they might be prime sites for further geological studies focusing on questions relatied to the history of sea level transgressions in the York region.

An enhanced knowledge of the underlying stratigraphy of the Research Reserve sites, obtained through deeper coring, would contribute both to the on-going efforts toward mapping the regional geology and toward understanding the local and regional ground-water systems. The geometry of the shallowest aquifers and aquacludes influences the pathways available for the transport of nutrients and other compounds. It already is known in general terms that the Impact Crater disrupted the deeper aquifers; however, post-depositional changes within crater-fill and overlying strata are less well known.

Establishment of suitable, permanent benchmarks to document elevation would enable long-term monitoring of subsidence. This monitoring would be in the form of precision leveling every few years. This knowledge of change in elevation when compared to measurements of local relative sea level would facilitate differentiation of the eustatic and isostatic components of changes in relative sea level and assist in quantifying local sea-level rise relative to climate change or other factors.

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York River Physical Oceanography and Sediment Transport

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ABSTRACT

The York River is a partially-mixed, microtidal estuary with tidal currents in the mid- to upper estuary approaching 1 m/s. The upper York near West Point is generally less stratified than the lower York near Gloucester Point because of the shallower depths and stronger currents found upstream. Fluctuations in salinity stratification in the York River at tidal, fortnightly and seasonal time-scales are associated with tidal straining, the spring-neap cycle, and variations in freshwater discharge, respectively. Estuarine circulation in the York River, which averages ~5 to 7 cm/s, is often modulated by moderate winds. Waves are usually insignificant, although occasional severe storms have a major impact. The York River channel bed is predominantly mud, while the shoals tend to be sandier, and the mid- to upper York is marked by seasonally persistent regions of high turbidity. Fine sediment is trapped in high turbidity regions in response to tidal asymmetries and local variations in stratification and estuarine circulation. More work is needed to better understand the linkages between physical oceanography, sediment transport and turbidity in the York River system, especially during high-energy events and in response to ongoing climate change.

PHYSICAL FEATURES

The York River extends from its mouth near the Goodwin Islands to its head approximately 50 km upstream at West Point (at the confluence of the Mattaponi and Pamunkey Rivers). Along most of its length, the York is characterized by a main channel bordered by well-developed shoals. Depths along the axis of the main channel of the York River vary from about 20 m near Gloucester Point to about 6 m near West Point, with a tendency towards decreasing depth with distance upstream (Figure 1). Along the central third of its length, the York also contains a secondary channel about 6 m deep, separated from the main channel by along-axis shallows that rise to about 4-m depth. The average depth of the York River downstream of West Point, including shoals, is 4.9 m (Cronin, 1971), and its average width is 3.8 km (Nichols *et al.*, 1991). Upstream of West Point, the channels of the Mattaponi and Pamunkey are much narrower, measuring only several hundreds of meters wide.

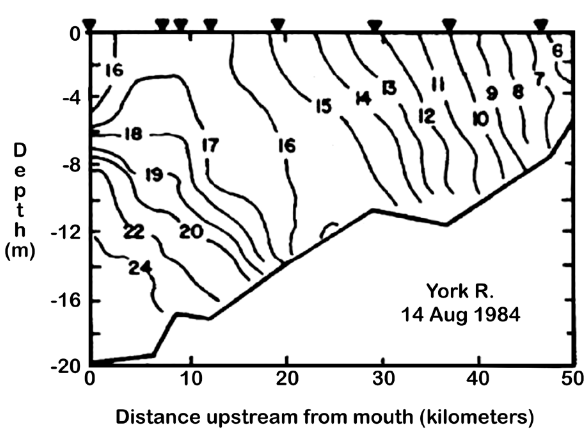

Figure 1. Typical salinity distribution along the York River (Figure 2 from Kuo and Neilson, 1987).

TIDES

The York River is a microtidal estuary with a mean tidal range at its mouth of 0.70 m, increasing to 0.85 m at West Point (Figure 2). After decreasing back to 0.75 m in the region of Sweet Hall, the range increases once more until approaching 1 m in the upper Pamunkey (Sisson *et al.*, 1997). Despite

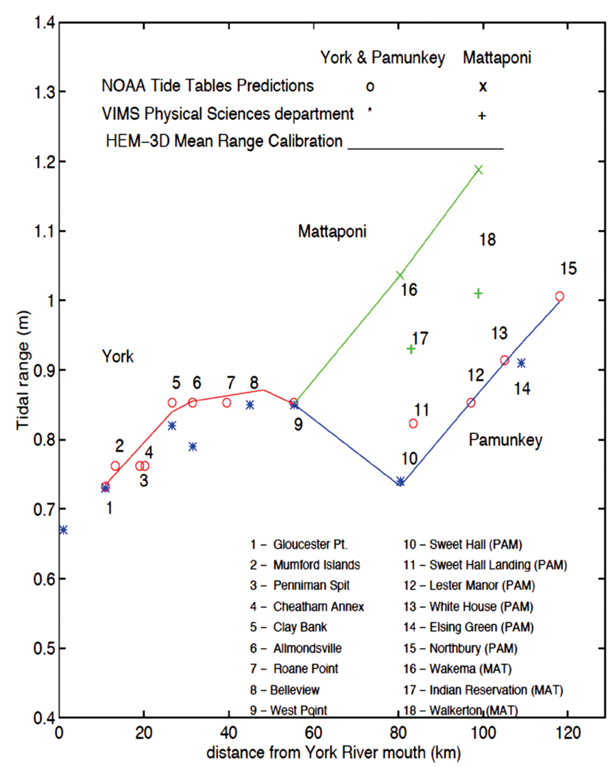

Figure 2. Comparison of tide range along the York, Pamunkey and Mattaponi from VIMS HEM-3D model output, VIMS gauge data, and NOAA tide table data (Figure 9 from Sisson *et al.*, 1999).

being classified as a microtidal system, tidal currents in the mid- to upper-York are strong enough to cause significant sediment suspension (Schaffner *et al.*, 2001). Figure 3 displays estimates of tidal current magnitude at spring tide as a function of distance up the York and Pamunkey. These estimates of tidal current strength are based on the methods of Friedrichs (1995) using cross-sectional areas and tidal volumes for the York and Pamunkey as presented by Cronin (1971). The magnitude of tidal currents increases with distance up the York River such that tidal currents in the mid- to upper-York are stronger than those typically found in microtidal estuaries. Tidal current strength also varies across the width of the estuary. For example, tidal currents are about twice as strong in the 10-m deep main channel of the York than at 3-m depths over the adjacent shoals (Huzzey and Brubaker, 1998). Tidal fronts often form for periods of a few hours over the tidal cycle at the channel-shoal transition due to differential along-channel advection of salinity by the tide.

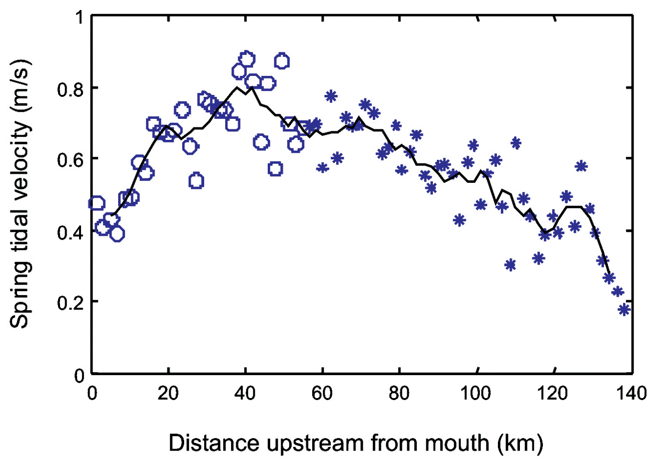

Figure 3. Spring tidal velocity amplitude as a function of distance up the York (o) and Pamunkey (*) rivers estimated from data presented by Cronin (1971). Solid line is a five-point running average.

RIVER INFLOW

Because of the relatively small watershed of the York River, the freshwater flow into the river is normally modest. Mean river discharge in the Pamunkey and Mattaponi at the USGS stream gauges near the heads of the tide are 28.7 m^3s^{-1} and 14.4 m^3s^{-1}, respectively (Shen and Haas, 2004), and the mean total discharge into the York from all sources is estimated to be 71 m^3/s (Nichols *et al.*, 1991). The 90th percentile high flow between 1942 and 2001 gauged for the Pamunkey plus Mattaponi totaled 107 m^3s^{-1}, whereas the 20th percentile low flow was just 9.2 m^3/s (Shen and Haas, 2004). One of the highest discharges on record is associated with Tropical Cyclone Isabel, when the Pamunkey plus Mattaponi gauged flow reached 421 m^3s^{-1} (Gong *et al.*, 2007). Despite the low mean freshwater discharge into the York relative to its cross-section, the influence of river flow on the dynamics of the estuary as a whole is still extremely important due to its effect on the salinity distribution. The location of head the salt intrusion, the overall degree of stratification, and the location and intensity of the estuarine turbidity maximum are all ultimately dependent on river inflow.

SALINITY - ALONG-CHANNEL DISTRIBUTION

Between its mouth and West Point, the York River encompasses the majority of the range of salinities characteristic of temperate estuaries. Bottom salinities along this gradient typically range from about 6 psu to 25 psu (see Figure 1). The transition to fresh water (≤ 1 psu) is normally found within the Mattaponi and Pamunkey between 60 and 90 km from the mouth of the York (Lin and Kuo, 2001; Shen and Haas, 2004). Although the precise location of the transition to fresh water varies with river discharge, the transition to fresh water along the Pamunkey commonly occurs near the Sweet Hall Marsh CBNERR site. Because of the relatively small watershed feeding the York River and much larger watershed feeding the neighboring Chesapeake Bay, regionally wet years can result in relatively fresher water being advected into mouth of the York from the lower Bay, resulting in a local reversal of the salinity gradient within the York River and a local maximum in salinity being found within the lower York itself (Haywood *et al.*, 1982).

SALINITY STRATIFICATION

The lower York is generally more stratified than the upper York (see Figure 1). This is because shallower depths and stronger tidal currents with distance upstream both favor greater mixing of the water column. Superimposed on the spatial gradient is a strong time-variation in stratification associated with the 14-day spring-neap tidal cycle. In the lower York, top-to-bottom stratification regularly exceeds 7 psu around neap tide and commonly is reduced to less than 2 psu around spring tide (Haas, 1977). In the middle York, the cycle in stratification is typically on the order of 3 psu at neap, decreasing to less than 1 psu around spring (Sharples *et al.*, 1994). In the middle and upper York, this stratification cycle is due to a competition between the tendency of gravitational circulation to increase stratification and the tendency of strong spring tidal currents to mix stratification away (Sharples *et al.*, 1994). Near the mouth of the York, advection of relatively fresh water in from the lower Chesapeake Bay may also play a role in enhancing destratification around spring tide (Hayward *et al.*, 1982).

Salinity stratification in the York River tends to increase over the course of the ebb and decrease over flood through a process known as tidal straining (Scully and Friedrichs, 2003, 2007a, b; Simpson *et al.*, 2005). Because tidal currents are stronger at the surface than at depth, ebb tides in the York River advect fresher surface water seaward over underlying saltier water, increasing stratification during ebb. Conversely, flood tides transport saltier surface water landward over relatively fresher water, decreasing stratification. Less stratification on flood results in more turbulence and sediment suspension on flood (i.e., tidal asymmetry), favoring up-estuary transport of sediment (Scully and Friedrichs, 2003). The presence of shoals on either side of the river and the relatively shallow secondary channel lead to strong variations in stratification across the width of the estuary as well. The shoals and secondary channel tend to be more well-mixed than the main channel, and along-channel fronts often form along steep lateral changes in bathymetry (Huzzey and Brubaker, 1988; Scully and Friedrichs, 2007a).

CIRCULATION AND RESIDENCE TIME

In the absence of wind or major discharge events, the mean estuarine circulation along the York River is relatively weak. Three-dimensional modeling suggests that time-averaged landward flow in the lower layer of the main channel of the York halfway to West Point under normal conditions is about 5 to 7 cm s^{-1} (Gong *et al.*, 2007). Relatively weak upstream flow in the main channel may be due in part to the presence of the neighboring shallower secondary channel. Increased stratification in the main channel during ebb tends to delay the turn to flood, enhancing seaward transport in the main channel (Scully and Friedrichs, 2007a).

Because of the low fresh water inflow and relatively weak mean circulation in the York River, residence times for dissolved materials such as fresh water or pollutants are relatively long. Based on numerical model simulations, Shen and Haas (2004) found that under mean flow it takes about 60 days for such material to be transported from the head of the tributaries to West Point, 85 days to be transported to the middle of the York, and 100 days to be transport out of the York River entirely. The residence times are cut nearly in half under high flow and more than doubled under low flow (Shen and Haas, 2004).

Down-estuary winds in the York River can strongly enhance the typical pattern of estuarine circulation, whereas up-estuary winds reduce and can even reverse the two-layer flow (Scully *et al.*, 2005, Figure 4). Down-estuary winds blowing at 5 m/s for a day or two can double the typical strength of the estuarine circulation. The enhanced circulation associated with down-estuary winds in turn increases estuarine stratification because fresher water from upstream is advected down-estuary over saltier water. Conversely, winds directed up-estuary reduce stratification and rapidly mix the water column. Because of this wind-induced straining of the salinity field,

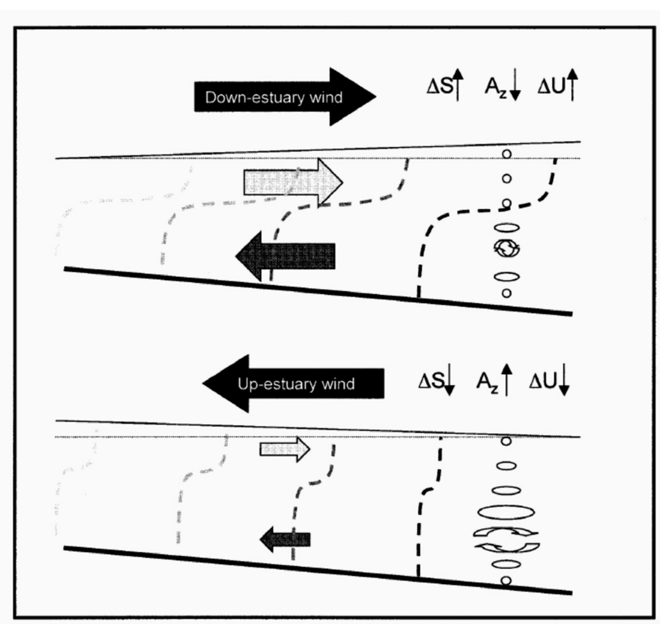

Figure 4. Conceptual model of wind-induced straining of salinity gradients in the York River and the responding two-layer circulation (Figure 6 from Scully *et al.*, 2005). DS is salinity stratification, AZ is the eddy viscosity (proportional to vertical mixing), and DU is the strength of the two-layer circulation. Arrows point in the direction the wind is blowing toward.

increased wind strength (up to a point) does not necessarily result in increased vertical mixing if winds are directed down-estuary. The degree of stratification present also affects the ability of the winds to mix the water column, with greater stratification being more difficult to mix away. If the water is only weakly stratified, 10 m s^{-1} winds in any direction will mix the water column. But if the water is already stratified, 10 m s^{-1} down-estuary winds may simply induce more straining and further stratify the water (Scully *et al.*, 2005).

EFFECTS OF WAVES AND STORMS

Except during occasional storms when strong winds line up with the axis of the estuary, waves are generally quite small in the York River. An analysis of the wind climate in the lower York estuary indicated that conditions favorable for wind wave growth exist only 3 to 4% of the time (Vandever, 2007). Observations of wave height over the course of 2006 found that significant wave height exceeded 0.30 m off Gloucester Point and 0.57 m off Goodwin Islands 1% of the time. A wave gage placed in 2-m water depth off the Catlett Islands CBNERR site from February to May 1996 documented only two events when significant wave height briefly exceeded 0.4 m, each with wave periods of 2 to 3 sec (Boon, 1996). Nonetheless, large waves can occur during extreme events. During Tropical Depression Ernesto in September 2006, significant wave height reached 1.7 m off Goodwin Islands and during Tropical Cyclone Isabel in September 2003, significant wave height reached 1.6 m at Gloucester Point (Vandever, 2007).

The response of the York River to Tropical Cyclone Isabel is particularly well documented (Brasseur *et al.*, 2005; Gong *et al.*, 2007). During Isabel, gauged river discharge into the York reached 412 m^3/s, winds at Gloucester Point reached over 40 m/s, and the local storm surge exceeded 2.0 m. The nearly coincident times of high tide, the storm surge and maximum wave heights resulted in more severe coastal damage locally than in either Tropical Storm Agnes or the hurricane of 1933. At the peak of the storm, water velocity near the mouth of the river was dominated by up-estuary wind driven flow, and normal ebb tides were not seen for over 12 hours. As a result of the high fresh water discharge, the York estuary changed from its typical partially-mixed state to a highly stratified system (Figure 5). The strength of seaward, tidally-averaged surface flow two days after the storm exceeded 20 cm/s. It took approximately four months for the salinity field in the estuary to completely recover to pre-Isabel conditions.

SEDIMENT DISTRIBUTION AND SUSPENSION

The beds of the main and secondary channel of the York River are predominantly mud, with the percentage of mud generally exceeding 80% (Nichols *et al.*, 1991; Figure 6). The shoals of the main channel and the Pamunkey and Mattaponi Rivers in general tend to be sandier, with the percentage of sand on the bed in these regions often exceeding 50%. In relatively open areas, waves routinely play a role in suspending sediment in water depths less than about a meter. But even in depths as shallow as two meters, tidal currents tend to dominate suspension in the York River (Boon, 1996). Suspended sediment concentrations in the lower water column are closely tied to the strength of the tidal current and the availability of easily suspended sediment on the bed. In the muddy reaches of the York secondary chan-

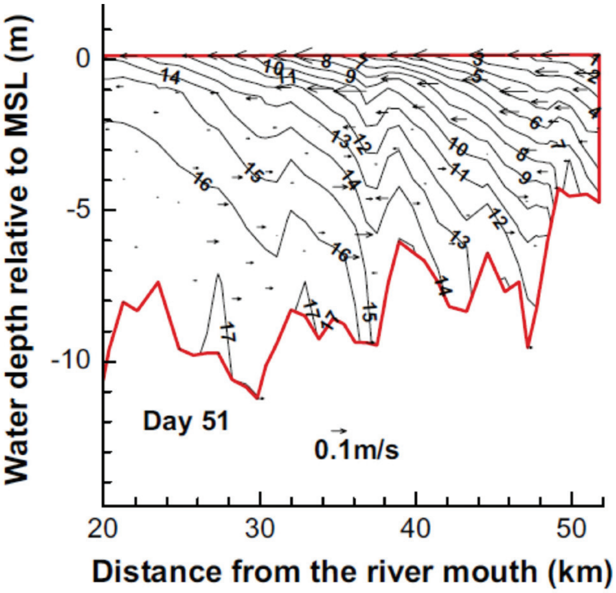

Figure 5. A 3D numerical simulation of the longitudinal distribution of tidally averaged salinity and velocity along the York River two days after the passage of Tropical Cyclone Isabel (Figure 13 from Gong *et al.*, 2007).

nel, Friedrichs *et al*. (2000) documented near-bed tidal suspensions regularly exceeding 1 gram/liter at peak tidal flow.

Persistent spatial patterns of fine sediment suspension are seen both across and along the York River. Because shallower areas tend to be more well-mixed, surface waters in shoal areas tend to be more turbid than is the case in deeper areas (Figure 7). There are also persistent along-estuary peaks in turbidity along the York River known as estuarine turbidity maxima (ETMs). The main ETM in the York River is typically located near the head of the salt intrusion. A secondary ETM is often found about 20 to 40 km from the mouth of the York where there tends to be an upstream decrease in stratification (Lin and Kuo, 2001). At slack water, sediment concentrations at the main ETM can reach 250 mg/liter near the bed and 50 mg/liter near the surface (Figure 8). Concentrations often exceed 100 mg/liter near the bed at the secondary ETM as well, but stratification usually prevents high concentrations from reaching the surface.

SEDIMENT TRAPPING

Trapping of fine sediment in these ETM regions is due in large part to local decreases in the strength of near-bed estuarine circulation. Estuarine circulation decreases with distance upstream if (i) the along-channel salinity gradient decreases, (ii) vertical stratification decreases, and/or (iii) water depth decreases. All three mechanisms contribute to sediment trapping at the main ETM, whereas (ii) and (iii) are more important at the secondary ETM (Lin and Kuo, 2001). Another mechanism that contributes to sediment trapping at the ETMs is tidal asymmetry. Because of interactions with gravitational circulation and stratification, the flood tide tends to be stronger and more turbulent than the ebb tide, and more sediment is suspended and moved landward on flood (Scully and Friedrichs, 2003, 2007b). This asymmetry becomes weaker as stratification and estuarine circulation decrease, leading to additional transport convergence and sediment trapping at the ETMs.

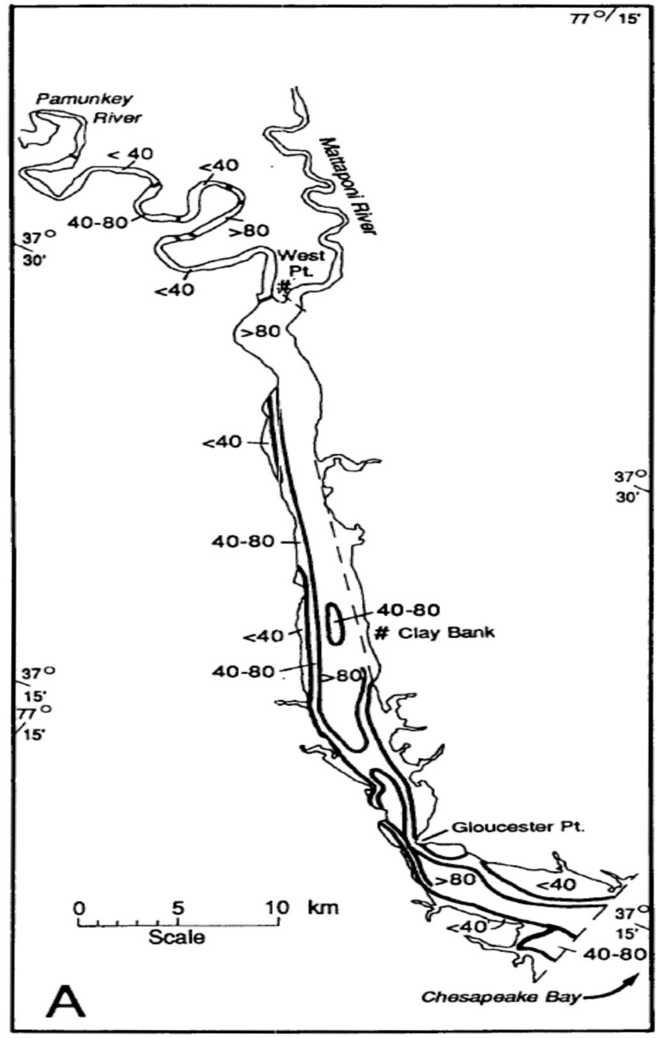

Figure 6. The spatial distribution of percent mud in the bed of the York River (Figure 6 from Nichols *et al.*, 1991).

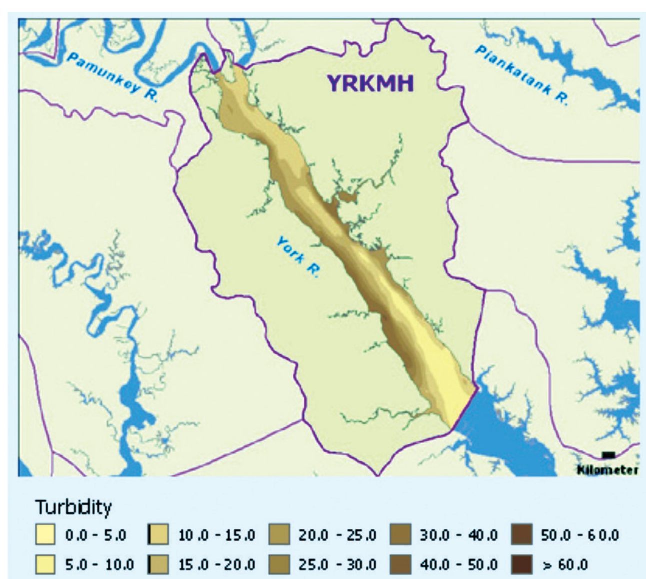

Figure 7. Surface turbidity measured on July 6, 2005 by CBNEERVA in units of NTU (http://www.vecos.org).

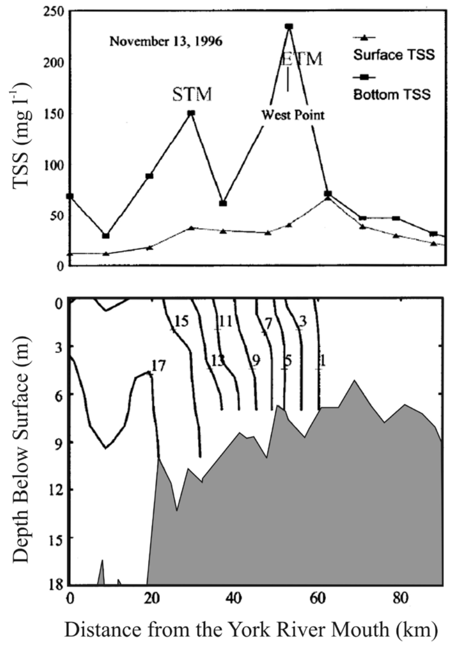

Figure 8. Total suspended sediment (TSS) concentrations collected 1 m above the bed and 1 m below the surface along with vertical salinity distributions at slack water along the York and Pamunkey Rivers (Figure 5 from Lin and Kuo, 2001).

The rate at which sediment is trapped within the York River is not entirely resolved. Nichols *et al*. (1991) estimated an influx of 0.22 x 10^6 tons year^{-1} of sediment into the York from the Pamunkey and Mattaponi, 0.05 x 10^6 tons year^{-1} from shoreline erosion, and 0.13 x 10^6 tons/year from the Chesapeake Bay. The input rate from the Bay was estimated by assuming transport rates to be similar to those better documented in the neighboring James and Rappahannock Rivers. Herman (2001) combined a decade of suspended sediment concentration measurements from water quality monitoring in the York with predicted tidal currents and estuarine circulation to estimate contributions to net sediment flux. Based on monitoring data, Herman (2001) calculated a larger net flux of 0.7 x 10^6 tons/year into the York from the Bay and concluded that this up-estuary flux was dominated by tidal asymmetries. However, Herman (2001) noted that this larger value may be biased by the relatively calm conditions associated with monitoring cruises, and net seaward transport of sediment may occur during storms.

FUTURE RESEARCH DIRECTIONS

More work is needed to better understand the linkages between physical oceanography, sediment transport and turbidity in the York River system, especially during high energy events. The potential effects of climate change, especially its effects on the frequency and intensity of storms in this region are not well known. The dynamics of mean circulation and the estuarine turbidity maxima in the York are reasonably well understood during calm conditions. However, preliminary results suggest the distribution of turbidity and net transport may be quite different under the influence of strong winds. Analysis of data from fair weather monitoring cruises suggests very high rates of landward sediment transport during fair weather, supporting speculation that major downstream sediment transport occurs during storms. Because fresh water discharge is still minor during most storms relative to the large cross-sectional area of the York, the specific processes that drive sediment downstream are still not clear. Other potential areas for research include the mechanisms that maintain sandy shoals versus muddy channels. Waves are too small in the York to regularly suspend sediment, even in areas as shallow at 2 m. Since tidal currents are stronger in deeper water, one might expect tidal suspension to eventually disperse fine sediment back toward the shoals. Are waves and wind-driven currents during major storms extremely important for removing mud from shoals? Or could tidal suspensions laden with fine sediment possibly be driven directly into deeper areas by down-slope gravity currents? Finally, recent work has highlighted the role of tidal asymmetries in controlling stratification and sediment transport in the York River. Additional work is needed to evaluate the importance of tidal asymmetry relative to more classical, density- driven estuarine circulation.

ACKNOWLEDGEMENTS

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Water Quality within the York River Estuary

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ABSTRACT

Key water quality management issues and threats within the Chesapeake Bay and its tidal tributaries include excess loadings of sediment and nutrients, and the introduction of toxic chemicals and microbial agents. Poor water clarity, principally controlled by suspended sediments and phytoplankton, is a persistent and widespread problem in the York River estuary with the oligohaline and middle mesohaline regions failing to meet submerged aquatic vegetation (SAV) habitat requirements (SAV criteria: ~10 NTU and TSS < 15 mg L^{-1}). Both the primary and more localized secondary estuarine turbidity maximum are associated with these regions where elevated surface (30-35 mg L^{-1}) and bottom (80-105 mg L^{-1}) water TSS levels are observed. While nonpoint agriculture sources dominate riverine sediment load inputs, tidal and nearshore erosion are a significant source of suspended sediment in the York River estuary. As with sediment, nonpoint agricultural sources dominate nutrient inputs and streamflow is a dominant controlling factor in explaining variability in annual loads. Within mainstem surface waters, TDN and TDP concentrations exhibit a decreasing trend with increasing salinity. TDN and TDP concentrations are on the order of 40-45 µmol L^{-1} and 1.2 µmol L^{-1}, respectively, in the tidal freshwater reaches of the Pamunkey and Mattaponi Rivers and 22-24 µmol L^{-1} and 0.6 µmol L^{-1} in the polyhaline regions of the York River. Mean DON exhibits little variation between salinity regimes. Seasonal phytoplankton biomass and productivity vary between salinity regimes with mean monthly peak chlorophyll *a* concentrations on the order of 9-10 µg L^{-1} in the tidal freshwater reaches, 14-18 µg L^{-1} in the transition zone below the freshwater region, 25-28 µg L^{-1} in the upper and middle mesohaline reaches, and 15 µg L^{-1} in the lower meso-polyhaline region. Based on DIN:DIP molar ratios and limited nutrient enrichment studies, tidal freshwater regions experience year-round phosphorus limitation, shifting to seasonal nitrogen limitation in the lower oligo, meso and polyhaline regions of the York River. Harmful algal bloom (HAB) producing dinoflagelletes have resulted in "red tides" that generally occur annually (summer, early fall) in the lower York River. With respect to low dissolved oxygen levels, hypoxia derived from oxidation of organic matter and sediment oxygen demand has also been observed repeatedly in the bottom waters of the lower, high salinity reaches when water temperatures exceed 20 °C. While studies have indicated limited toxic chemical contamination, mercury and PCB fish consumption advisories and restrictions have been issued within the York River estuary. Mercury impacted regions of the Mattaponi and Pamunkey Rivers receive significant wetland drainage that can enhance the potential for bioaccumulation of mercury in fish. Sediments in the York River proper exhibit PCB levels ranging from 1-5 ppb with more elevated levels (25 ppb) being observed in some contributing tidal creeks. In contrast to mercury where atmospheric deposition is a primary pathway, PCBs are generally released into the environment from runoff processes occurring at hazardous waste sites. With varying sources of fecal pollution, 20 percent (31.1 km^2) of the York River's assessed shellfish waters has been designated as impaired. Condemned waters are restricted to major industrial and defense facility sites, and contributing smaller tidal creek systems.

GENERAL PHYSICAL CHARACTERIZATION

The York River is the Chesapeake Bay's fifth largest tributary in terms of flow and watershed area (≅ 6900 km^2). The York River basin is located within Virginia's Coastal Plain and Piedmont physiographic provinces and includes all of the land draining into the Mattaponi, Pamunkey and York Rivers. Land use is predominantly rural in nature with forest cover accounting for 61% of the basin's cover, agricultural lands accounting for 21%, developed lands 2%, wetlands 7%, barren lands 1% and water accounting for the remaining 8% (Chesapeake Bay Program watershed profiles: http://www.chesapeakebay.net). Percentage of impervious surfaces, a component of developed lands, is on the order of 1%. Average annual precipitation rates within the watershed varies from 111 cm in the upper reaches of tidal waters (Walkerton; 1932-2007) to 121 cm in lower reaches (Williamsburg; 1948-2007).

The York River estuary receives freshwater from its two major tributaries whose confluence is at West Point located approximately 52 km from the rivers mouth near the Goodwin Islands component of the Reserve. Long-term daily mean streamflow is 16.3 m^3 sec^{-1} for the Mattaponi (USGS Station: 01674500; 1942-2007) and 30.7 m^3 sec^{-1} for the Pamunkey (USGS Station: 01673000; 1972-2007) Rivers (Figure 1). The York River estuary also receives freshwater input from a large number of smaller ungaged subbasins and direct groundwater discharge to tidal waters; approximately 35% of the York River basin is below USGS gaging stations (Seitz, 1971). The base flow index, a measure of groundwater flow within non-tidal portions of the rivers and expressed as the ratio of base flow to total streamflow, is estimated at 0.46 for the Pamunkey and 0.58 for the Mattaponi River (Bachman *et al.*,, 1998).

The York River system is classified as a microtidal, partially mixed estuary. The mean tidal range is 0.7 m at its mouth and increases to over 1 m in the upper tidal freshwater regions of the Mattaponi and Pamunkey Rivers (Sisson *et al.*,, 1997). The tidal prism has been estimated at 110 million m^3 at the mouth and 35 million m^3 at West Point (Sturm and Neilson, 1977).

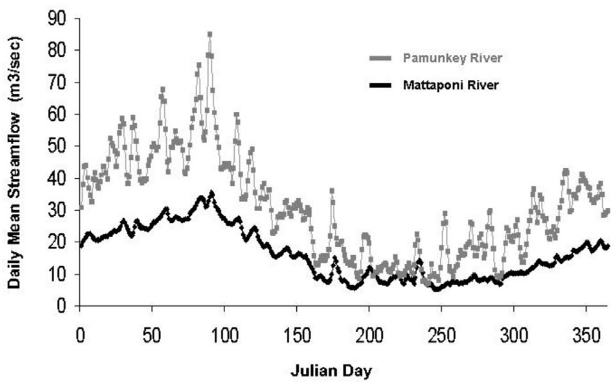

Figure 1. Longterm daily mean streamflow for the Mattaponi and Pamunkey Rivers.

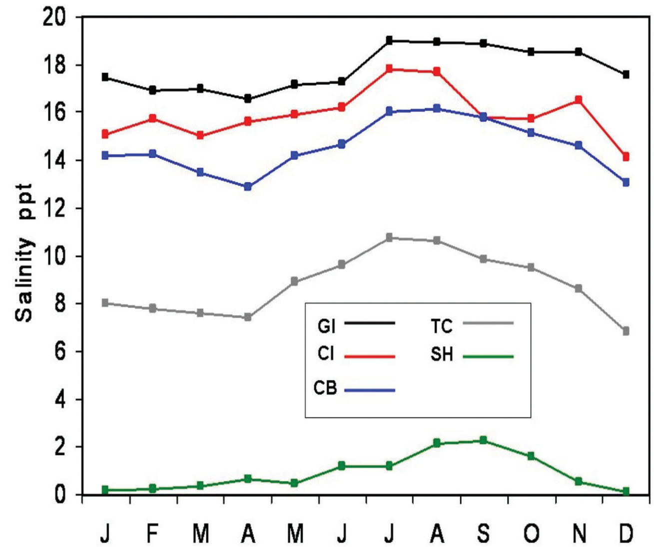

Figure 3. Seasonal salinity patterns for Reserve components and Clay Bank. GI: Goodwin Islands, CI: Catlett Islands, TC: Taskinas Creek, SH: Sweet Hall Marsh and CB: Clay Bank. Data sources: NOAA/NERRS 15 minute continuous data for SH, TC, CB and GI; VIMS shoal data (1-3 samplings per month).

Because the Mattaponi and Pamunkey Rivers do not exhibit a prominent fall-line as delineated by other Bay tributaries, the uppermost extent of tidal propagation is somewhat variable and on the order of 120 km upriver on the Mattaponi and as far as 150 km upriver on the Pamunkey (Lin and Kuo, 2001). The phase of tide lags with distance up the estuary. The tide is about 2.2 hours behind the mouth of the estuary (Goodwin Islands) at the confluence of the Mattaponi and Pamunkey Rivers (West Point; 52 km upriver), and 3.9 hours behind at the Sweet Hall Marsh (75 km upriver). Residence time, defined as the time taken for an element to be discharged from the estuary, in the York River estuary is dependent on freshwater discharges rates. Shen and Haas (2004) have estimated residence times are the order of 45 and 90 days for material discharged at the headwaters of the Mattaponi and Pamunkey Rivers during high (upper 90^{th} percentile) and mean flows, respectively.

Salinity distribution along the York River estuary ranges from tidal freshwater to polyhaline regimes (Figure 2). Seasonal salinity (2003-2006) patterns specific to the Reserve components are presented in Figure 3 and generally indicate tidal freshwater to oligohaline conditions at Sweet Hall Marsh (SH), mesohaline conditions at Taskinas Creek (TC) and Catlett Island (CI), and a meso to polyhaline salinity regimes at Goodwin (GI) Islands. Interannual variations in hydrologic budgets and large-scale episodic events (e.g., tropical cyclones) can have a significant impact on the short and long-term salinity patterns within the estuary. This can be exemplified by the salinity record at Sweet Hall Mash during historic dry (CY 2002, annual precipitation: 78 cm) and wet (CY2003, annual precipitation: 191 cm) years; tropical storm Isabel made landfall on September 18, 2003 (Figure 4). Annual streamflow values for the Mattaponi and Pamunkey Rivers were 0.20 and 0.36 × 10^6 m^3 day^{-1} in CY 2002, respectively, and 1.92 and 4.09 × 10^6 m^3 day^{-1} in CY 2003.

Vertical salinity stratification and homogeneity has been shown to regularly oscillate with the spring-neap tidal cycle in the lower and upper York River estuary (Haas, 1977; Sharples,

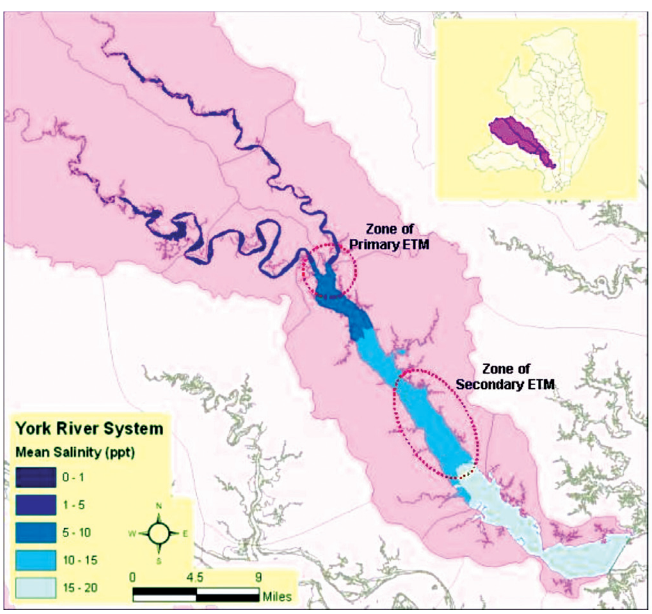

Figure 2. Mean salinity map of York River estuary based on monthly (April-October) Dataflow cruises of 2003, 2004 and 2005 and general locations of primary and secondary ETM.

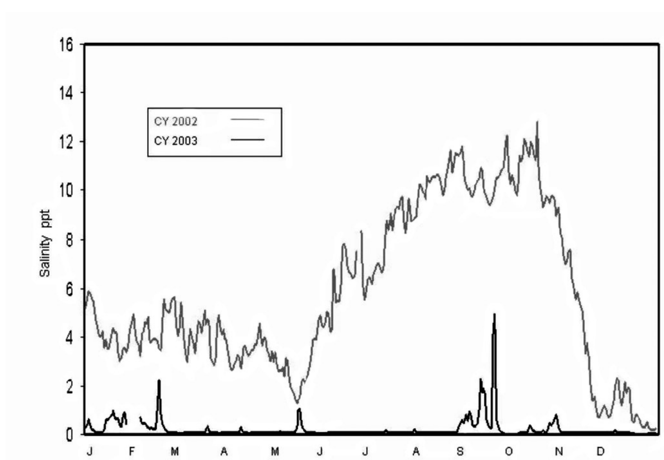

Figure 4. Daily mean salinity values at Sweet Hall Marsh for CY 2002 and 2003. (Figure from Reay and Moore 2005).

et al., 1994). Stability of the water column is controlled by processes that support stratification (e.g., freshwater induced density gradient, decreased turbulent mixing during neap tides and local surface heating) and processes that induce vertical mixing (e.g., elevated tidal action during spring tides and wind driven shear stresses). With respect to water quality, periodic and episodic vertical homogeneity and stratification of the water column is significant. Mixing of the water column can result in the reintroduction of nutrients to surface waters and subsequent enhanced phytoplankton growth (Webb and D'Elia, 1980; Haas *et al.*, 1981) and replenishment of oxygen to deeper waters (Kuo *et al.*, 1991). Conversely, stratification can lead to low dissolved oxygen conditions in bottom waters and influence the development of secondary turbidity maximums (Lin and Kuo, 2001).

The York River estuary can exhibit both a primary (ETM) and a more localized secondary estuarine turbidity maximum (STM) where suspended sediments occur at greater concentrations than observed either upriver or seaward (Figure 2; Lin and Kuo, 2001). The ETM is situated near the confluence of the Mattaponi and Pamunkey Rivers at the town of West Point, VA and the STM occurs within the region about 20 to 40 km from the mouth of the York River estuary. Resuspension of the bottom mud layer in the mid-region of the York River is believed to be a primary sediment contributor to the STM. The turbidity maximums may shift seasonally, migrating upriver during periods of low freshwater discharge.

BAY-WIDE WATER QUALITY ISSUES AND CRITERIA

Degradation of marine and estuarine environments is of global concern and the Chesapeake Bay along with its York River subestuary is no exception. Water quality may be affected by anthropogenic factors such as point and nonpoint source inputs as well as natural events such as excessively wet years and large-scale storms. A growing population along with associated land use changes are primary factors causing water quality and habitat degradation in the Bay's watershed, its tributaries and the Bay proper. Key water quality management issues and threats to the Bay system include:

- excess sediments which result in degraded habitat, reduce water clarity, and serve to transport toxic materials, pathogens and nutrients to water resources;
- excess nutrients, both nitrogen and phosphorus, that stimulate algal blooms and lead to oxygen deprived waters and reduced water clarity;
- introduction of toxic chemicals (e.g., mercury, PCBs, pesticides) and associated health impacts on wildlife and humans; and
- microbial agents.

In place of its traditional sediment and nutrient percent reduction strategy to assess water quality and contaminant input trends, the multi-state and agency Chesapeake Bay Program (CBP) has recently adopted a new habitat or designated use approach to more clearly define current water quality and develop strategies to achieve desired results (USEPA, 2003). Specific water quality criteria (i.e., water clarity, dissolved oxygen and chlorophyll *a*) are applied to five Bay habitat zones (i.e., spawning and nursery grounds, shallow water, open water, deep water and deep channel) (Figure 5) at specified times of the year depending on the needs of key Bay resources. Dissolved oxygen criteria are presented in Table 1 and water clarity criteria are presented in Moore of this Special Issue. With the exception of numeric criteria for specific regions of the James River, chlorophyll *a* criteria is based on narrative criteria that suggests that concentrations shall not exceed levels that result in ecologically undesirable consequences (e.g., reduced water clarity, low dissolved oxygen, food supply imbalances, or proliferation of undesirable species potentially harmful to aquatic or human life) or otherwise render tidal waters unsuitable for designated uses.

SEDIMENT

Recent sediment water quality status reports indicate continued degraded conditions in the Chesapeake Bay and York River subestuary. Based on 2005 estimates, agriculture lands contributed 62% of the sediment load to the Bay followed

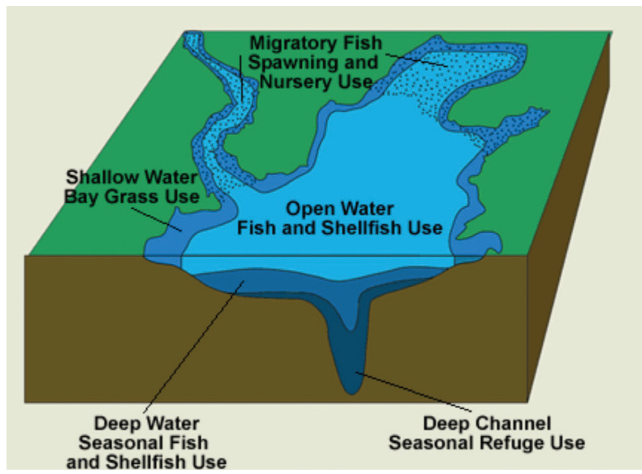

Figure 5. Oblique view of the Chesapeake Bay and tidal tributaries identifying principal habitat zones. Image from the Chesapeake Bay Program.

Table 1. *Summary of CBP dissolved oxygen criteria by habitat zone (USEPA 2007).*

Habitat Zone	Dissolved Oxygen	Temporal/Spatial Application
Spawning and nursery grounds	• 7 day mean: ≥ 6 mg L^{-1} Instantaneous minimum: ≥ 5 mg L^{-1} • Apply shallow-water/open-water criteria	Feb – May / 0-0.5 ppt Jun - Jan
Shallow water	• Apply open water criteria	Year-round
Open water	• 30 day mean: ≥ 5 mg L^{-1} • 30 day mean: ≥ 5.5 mg L^{-1} • 7 day mean: ≥ 4 mg L^{-1} Instantaneous minimum: ≥ 3.2 mg L^{-1}	Year-round; >0.5 ppt Year-round; 0-0.5 ppt Year-round
Deep water	• 30 day mean: ≥ 3 mg L^{-1} 1 day mean: ≥ 2.3 mg L^{-1} Instantaneous minimum: ≥ 1.7 mg L^{-1} • Apply open water criteria	Jun - Sep Oct - May
Deep channel	• Instantaneous minimum: ≥ 1 mg L^{-1} • Apply open water criteria	Jun - Sep Oct - May

by forested (20%) and urban/suburban (18%) lands (CBP 4.3 Watershed model results). Long-term (1985-2006) sediment concentration trends at primary CBP River Input Monitoring Program (RIM) stations (located at gaging stations above the point of tidal influence), which have been adjusted to reflect changes in river flow, are presented in Figure 6. Data from these monitoring stations generally show decreasing or no significant trends in flow adjusted sediment concentrations. Exception occurred in the Pamunkey River where a significant increasing trend (reported percent change: 85%; 1989-2006) was observed (Langland *et al.*, 2007).

Based on Chesapeake Bay water quality and watershed model simulations, York River basin total sediment input is on the order of 1.1-1.5 × 10^8 kg (does not include loading from shoreline erosion). Temporal changes in sediment and nutrient loads from the York River's primary tributaries are primarily a function of streamflow variability and changes in land use and/or management strategies over the longer term. Between 1985 and 2006, mean and ranges of annual sediment loads at CBP RIM stations on the Pamunkey River were 40.0 × 10^6 kg yr^{-1} and 1.6-104.0 × 10^6 kg yr^{-1}, respectively (Langland et al., 2007; determined from graphics). During this same period, mean and range of sediment loads were 5.2 × 10^6 kg $yr^{-1}$and 0.4-10.5 kg yr^{-1} for the Mattaponi River. Lowest sediment loads occurred during the regions historic dry year (2002) and peak sediment loads were associated with the historic wet year (2003) on the Pamunkey River.

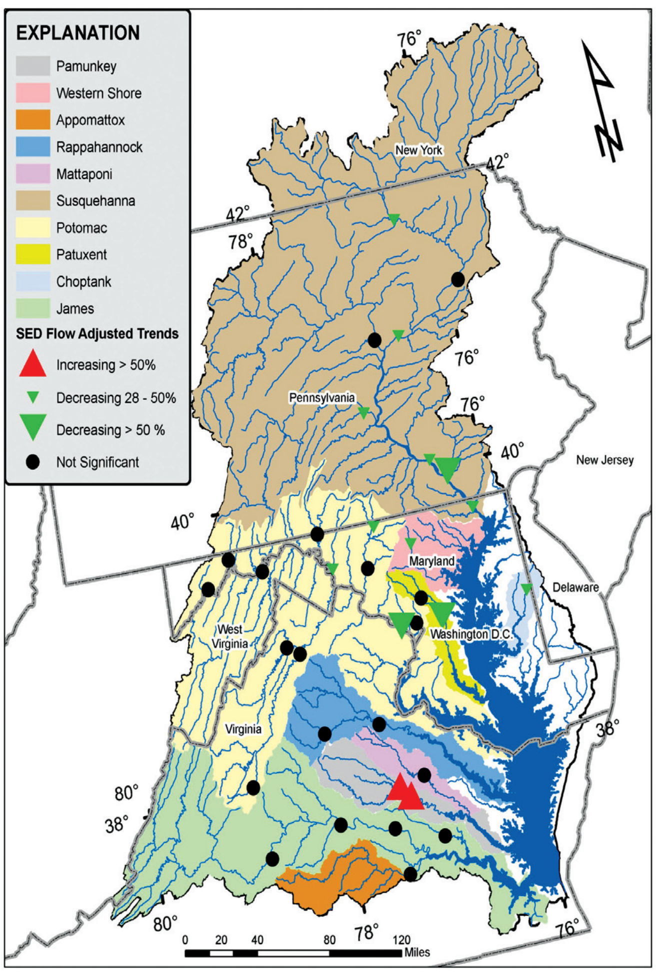

Figure 6. Long-term (1985-2006) selected RIM station flow adjusted sediment concentration trends. Image from the Chesapeake Bay Program.

Nonpoint agriculture sources of sediment dominate (52%) load inputs to the York River system, followed by forested (26%) and mixed open (14%) lands; urban runoff contributions are estimated at 8% (CWVa, 2005). Trend analysis of sediment loadings to the York River show a 21% decrease in nonpoint sources between 1985-2004 (Dauer *et al.*, 2005). Data specific to the York River watershed suggest annual sediment losses on the order of 9600 kg ha^{-1} for cultivated cropland, 2700 kg ha^{-1} for uncultivated cropland and 2600 kg ha^{-1} for pasture lands (NRCS, 1992). To put undisturbed forested land use in perspective, erosion rates for U.S. East Coast are on the order of 112-224 kg ha^{-1} (Patrick, 1976).

Sediment sources are not limited to watershed sources (e.g., upland surface and stream corridors erosion) but also includes tidal erosion from direct tide and wave action, ocean and aeolian input, and that of internal biogenic origin. Tidal erosion, which includes both fastland (land above tidal water often called shoreline) and nearshore erosion (sediment within shallow waters adjacent to shorelines), is a significant source of suspended sediment in many portions of the Bay and its tributaries (USEPA, 2005). With respect to the York River system, characterized by relatively low water discharge rates and basin slopes, tidal erosion is the dominant sediment source. Based on summarized model data, annual estimates of silt/clay sediment loads are on the order of 0.1 million MT from the York River watershed above the fall-line, 0.1 million MT from the watershed below the fall-line and 0.55 million MT from tidal erosion (USEPA, 2005, modified from Langland and Cronin, 2003); rivers generally do not have sufficient energy to transport gravel and sand through their tidal reaches. Reported long-term annual shoreline erosion rates for the York River are 15 and 30 cm for the north and south shore, respectively (Bryne and Anderson, 1976).

Spatial variations in turbidity, a qualitative measurement of the effect that suspended solids has on the transmission of light through water, are evident in the shallow waters of the York River estuary (see Friedrichs, Figure 7 of this Issue). Mean monthly turbidity values from shallow water stations in various salinity regimes are presented in Figure 7. Lower monthly mean values are associated with the higher salinity regions (i.e., polyhaline, range: 5-10 NTUs; and lower mesohaline region of the York River, range: 4-20 NTUs) and the tidal freshwater regions (range: 7-27 NTUs) of the estuary. Elevated monthly mean values are associated with the upper mesohaline (range: 11-76 NTUs) and oligohaline (range: 23-87 NTUs) regions of the estuary that contain both the ETM and STM.

Figure 8 depicts summarized ten-year (1997-2006) surface and bottom water total suspended solids (TSS) concentrations of selected Pamunkey, Mattaponi and York River main-stem stations. As with shallow water turbidity, reduced mean surface TSS concentrations were associated with the high salinity regions the River's mouth (<10 mg L-1) and lower mesohaline (17 mg L-1), and the tidal freshwater reaches of the Pamunkey (19 mg L-1) and Mattaponi Rivers (11 mg L-1). The transitional (36 mg L-1) and upper mesohaline (27 mg L-1) regions which include the general locations of the ETM and STM, respectively, exhibit elevated surface water TSS concentrations Particularly within the transitional and mesohaline regions of the river, bottom waters associated with the ETM and STM ex-

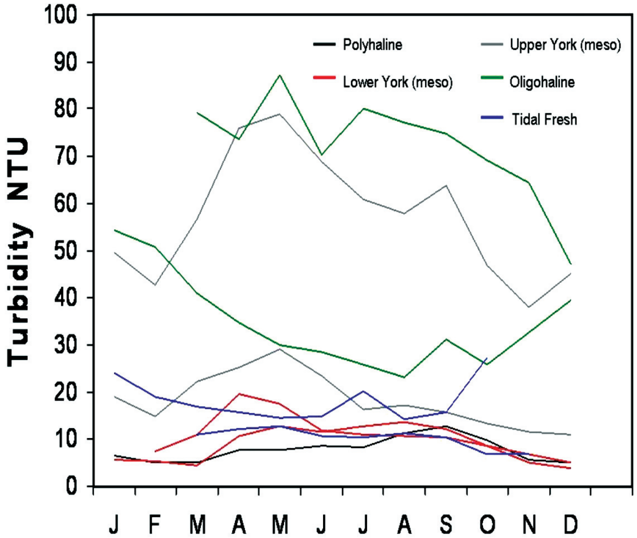

Figure 7. Mean monthly turbidity values for near continuous shallow water monitoring stations in the polyhaline (Goodwin Island), lower York mesohaline (Gloucester Point and Yorktown), upper York mesohaline (Clay Bank and Taskinas Creek), oligohaline (Sweet Hall Marsh and Muddy Point) and tidal freshwater (White House and Walkerton) reaches of the estuary. Data source: NOAA/NERRS SWMP program: 2003-2006; note: data availability for some stations was from 2003-2005 and may not have included all months.

hibited elevated mean TSS concentrations on the order of 80-105 mg L-1. Poor water clarity is a persistent and widespread problem in the York River system (Dauer *et al.*, 2005) and a principal factor regulating the growth and distribution of submerged aquatic vegetation (SAV). Light attenuation is principally controlled by interactions between plankton and suspended sediments. Based on turbidity (~10 NTU) and TSS (< 15 mg L-1; Batiuk *et al.*, 1992) SAV habitat requirement criteria, much of the York River system (e.g., transitional/oligohaline and middle mesohaline York) fail to meet SAV habitat requirements. High salinity regions in the lower York meet criteria

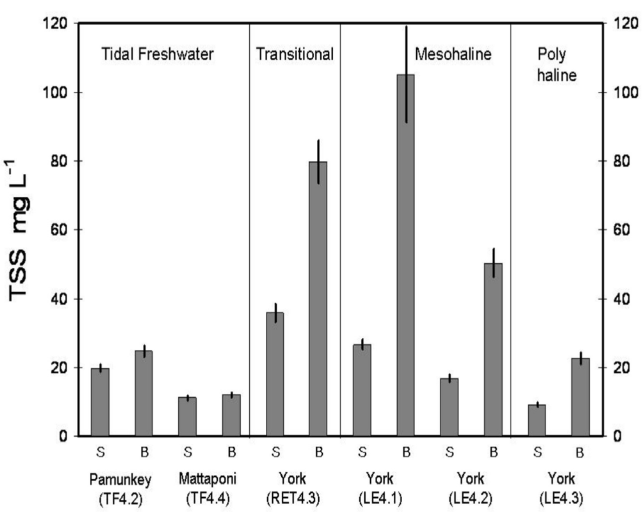

Figure 8. Long-term (1997-2006) TSS concentrations for surface (S) and bottom (B) waters at selected York River estuary sampling stations. Error bars: ± one SEM. Data source: Chesapeake Bay Program.

and much of the tidal freshwater reaches are marginal (Dauer *et al.*, 2005). For greater detail on SAV distribution, water quality habitat criteria and restoration see Chapter 6 of the document.

NUTRIENTS

As with sediments, nutrient water quality status reports indicate continued degraded conditions in the Chesapeake Bay and York River subestuary. Agricultural land uses continue to dominate nutrient load nutrient contributions to the Bay system. Based on 2005 estimates, agriculture fertilizer and manure sources contributed 34% and 45% of the nitrogen and phosphorus load to the Bay, respectively (CBP 4.3 Watershed model results). Atmospheric sources of nitrogen such as nitrous oxide emissions from vehicles, electric utilities and industry and ammonia contributions from livestock and fertilized soils are significant and responsible for approximately 30% of the nitrogen load to the Bay. Other significant contributors of nitrogen and phosphorus include municipal and industrial wastewater, responsible for approximately 20% of the annual loads, and fertilizer loads from urban/suburban lands. Long-term (1985-2006) nitrogen and phosphorus concentration trends at primary Bay tributary RIM stations, which have been adjusted to reflect changes in river flow, are presented in Figures 9 and 10, respectively (Langland *et al.*, 2007). Data from these monitoring stations generally show decreasing or no significant trends in flow adjusted nitrogen and phosphorus concentrations. Flow adjusted total nitrogen (TN) concentrations for the Mattaponi River did show a significant reduction with a reported change of -10%. Exceptions or increasing trends for nitrogen were observed in the Pamunkey River (reported change: 20%) and for phosphorus in the Potomac, Pamunkey (reported change: 122%), Appomattox (a tributary of the James River) and the Choptank Rivers.

As with riverine sediment loads, streamflow was a dominant controlling factor in explaining variability in annual nutrient loads. Between 1985 and 2006, mean and ranges of annual TN loads at RIM stations on the Pamunkey River were 6.8×10^5 kg yr^{-1} and 0.9-13.2 $\times 10^5$ kg yr^{-1}, respectively (Langland *et al.*, 2007). During this same period, mean and range of nitrogen loads were 2.9×10^5 kg yr^{-1}and 0.4-4.9 $\times 10^5$ kg yr^{-1}for the Mattaponi River. With respect to total phosphorus (TP), load mean and ranges were 7.97×10^4 kg yr^{-1} and 1.22-18.98 $\times 10^4$ kg yr^{-1} for the Pamunkey and 2.66×10^4 kg yr^{-1} and 0.32-4.59 $\times 10^4$ kg yr^{-1} for the Mattaponi River. Lowest nutrient loads occurred during the regions historic dry year (2002), peak nitrogen loads were associated with the historic wet year (2003) and peak phosphorus loads occurred in 2003 on the Pamunkey River. Estimates of TN and TP loads to the entire York River basin are on the order of 3.5×10^6 kg and 3.4×10^5 kg, respectively (Dauer, 2005; CWVa, 2005). Between 1985 and 2006, median TN concentrations were 47.1µmol L^{-1} (10th percentile: 34.3 1µmol L^{-1}; 90th percentile: 71.6 1µmol L^{-1}) at the RIM station on the Pamunkey River and 41.4 µmol L^{-1} (10th: 29.3; 90th: 57.1) on the Mattaponi River (Langland et al., 2007). Median TP concentrations were 2.26 µmol L^{-1} (10th: 1.00; 90th: 4.55) for the Pamunkey and 1.61 µmol L^{-1} (10th: 0.97; 90th: 2.13) for the Mattaponi Rivers.

Results of CBP watershed model simulations (1985 and 1998) indicate that agriculture (range: 38-46%); urban areas (31-32%) and forested lands (15-20%) were the dominant nitrogen contributors in the Pamunkey and Mattaponi subba-

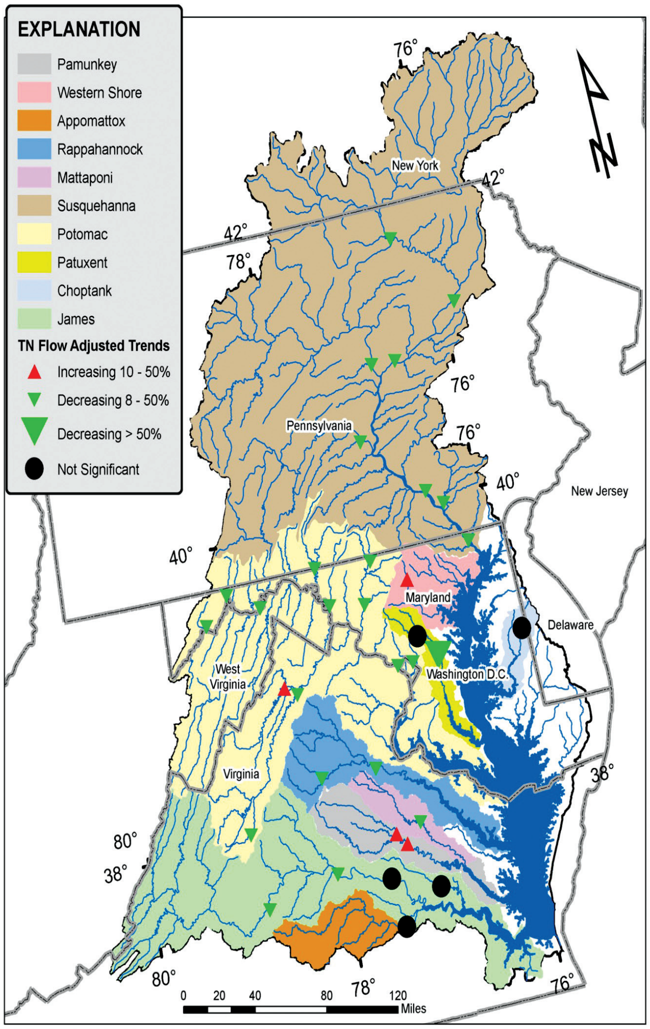

Figure 9. Long-term (1985-2006) selected RIM station flow adjusted total nitrogen concentration trends. Image from the Chesapeake Bay Program.

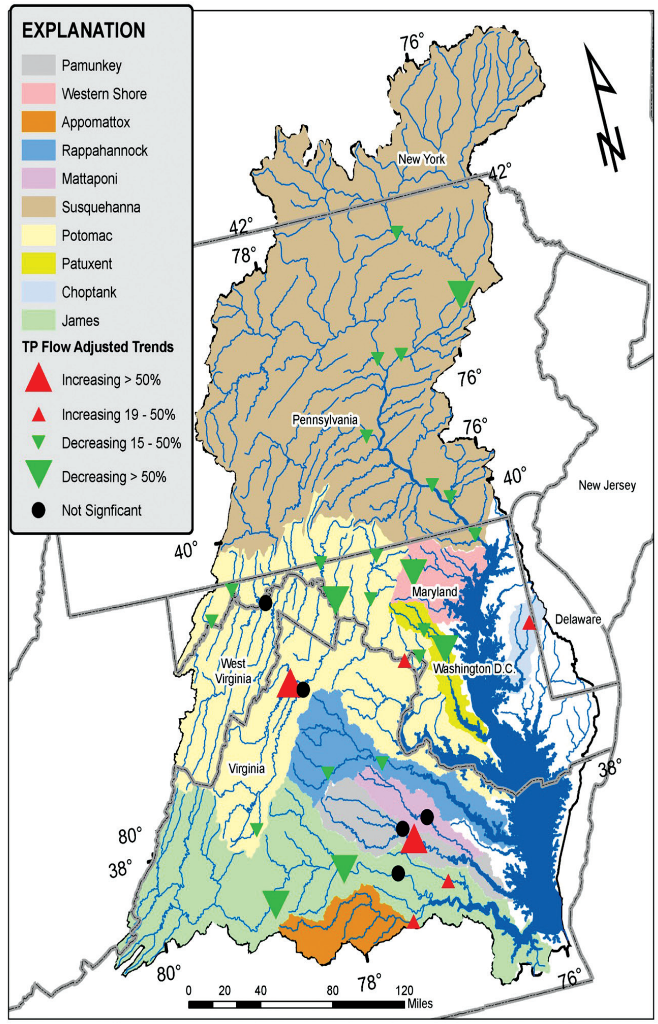

Figure 10. Long-term (1985-2006) selected RIM station flow adjusted total phosphorus concentration trends. Image from the Chesapeake Bay Program.

sins (Sprague *et al*., 2000). Point sources were more variable between the Pamunkey (2-10%) and Mattaponi (0-1%) Rivers; point source loading estimates increased dramatically in the Pamunkey River basin in 1998. Septic tank loadings ranged between 4-7% and direct atmospheric nitrogen deposition accounted for approximately 1%. With respect to phosphorus, agriculture (range: 55-76%) and urban areas (18-22%) were the dominant phosphorus contributors in the river subbasins; forested land contributions varied from 5-8%. Phosphorus point source contributions varied 11 to 18% in the Pamunkey and 0-5% in the Mattaponi basin; 1998 contributions increased by approximately 5% from 1985 to 1998. Septic tank contributions were insignificant and direct atmospheric phosphorus deposition accounted for approximately 1-2%. Trend analysis of TN loadings to the York River show an 18% decrease in nonpoint sources and a modest 1% increase in point sources between 1985-2004 (Dauer *et al.*, 2005). With respect to TP loadings, Dauer *et al.* (2005) reported a 19% decrease in nonpoint and 63% decrease in point source loadings since 1985.

In addition to interannual variability, nitrogen loads and concentrations generally exhibit strong seasonal patterns. Total dissolved nitrogen (TDN) and phosphorus (TDP) loads and concentrations for the Pamunkey River RIM station are presented in Figure 11 for the time period 1997 to 2006. TDN loads display a strong positive correlation with streamflow, with spring peak values followed by recession through the summer and gradual increase through fall and winter. It should be noted that elevated long-term discharge rates in September are in response to periodic large-scale storms (e.g., hurricanes and tropical storms) that impact the region. In contrast, TDN concentrations (e.g., particularly nitrate) are often high during periods of low flow, suggesting significant groundwater input. Groundwater nitrogen concentrations vary by land use with coastal agricultural lands displaying elevated values. Reported mean agricultural site values for dissolved inorganic nitrogen (DIN) ranged from 200-1085 µmol L^{-1} as compared to forested lands where values ranged from 9-89 umol L^{-1} (MacIntyre *et al*., 1989; Simmons *et al*., 1992; Reay *et al*., 1992; Gallagher *et al*., 1996). Developed lands utilizing on-site wastewater disposal systems (e.g., septic tanks) also pose a risk to ground water resources with drainfield DIN levels on the order of 5000 µmol L^{-1} (Reay, 2004). TDP loads and concentrations follow

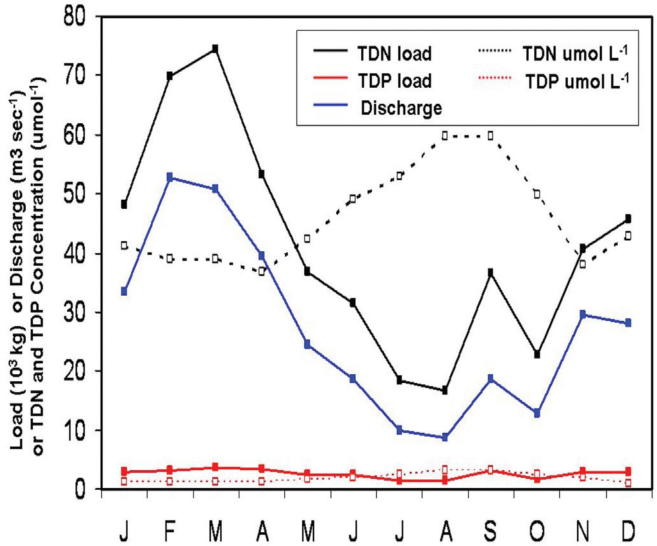

Figure 11. Ten year (1997-2006) monthly mean total dissolved nitrogen and phosphorus concentrations and loads for the Pamunkey River RIM station.

similar seasonal patterns and relative percent changes as exhibited by TDN. Nitrogen and phosphorus ratios of riverine input are important and have implications with respect to phytoplankton distribution and productivity. Seasonal variations in TDN:TDP of riverine input show elevated ratios in winter (TDN:TDP ratio: 35) and spring (ratio: 30) and declining in summer (ratio: 20-25) and fall (ratio: 20).

Within mainstem surface waters of the York River estuary, TDN levels show a decreasing trend with increasing salinity (Figure 12). Mean TDN levels, for the time period 1997-2006, within the tidal freshwater reaches are on the order of 40 μmol L^{-1} (Mattaponi) and 45 μmol L^{-1} (Pamunkey) and decrease to 22-24 μmol L^{-1} in the lower meso and polyhaline regions. While the mean dissolved organic fraction (DON) exhibits little variation between salinity regimes (mean range: 17-22 μmol L^{-1}), DIN shows a clear decrease as one moved from tidal freshwater to polyhaline regions of the estuary. It should be noted that both the addition of DIN and DON can stimulate algal blooms. As with TDN, mean 10 year TDP concentrations (Figure 13) decrease with increasing salinity, from approximately 1.2 μmol L^{-1} at the selected tidal freshwater stations to 0.6 μmol L^{-1} in the polyhaline region. Aside from the tidal freshwater stations where the inorganic and organic fractions of TDP where relatively similar, inorganic phosphorus (primarily PO_4) dominated the organic fraction whose mean value was approximately 0.2 μmol L^{-1} throughout the transitional to polyhaline regions. Regarding SAV water quality criteria, the meso and polyhaline regions of the York River meet DIN (< 10.7 μmol L^{-1}) and DIP criteria (< 0.65 μmol L^{-1}).

Daeur *et al.* (2005) provide the most current report on nitrogen and phosphorus status and trends for the York River estuary. Surface water total nitrogen status, utilizing 2001-2004 data and comparing to Bay-wide benchmarks, was fair for all segments (upper tidal freshwater to lower York River) while bottom waters were fair to good in the Mattaponi and Pamunkey Rivers and poor in the middle and lower York River segments. Surface water total phosphorus status was good in the upper tributaries, fair in the lower tributary segments and fair to poor in the York River segments. Status of bottom total phosphorus was generally more degraded as compared to surface waters in the lower tributary reaches and the York River. Concerning long-term trends (1985-2004) or post 1994 trends, Daeur *et al.* (2005) reported that degrading trends in total nitrogen were detected in all surface and most bottom waters (lower Mattaponi showed no significant trend) segments within the York River estuary. As with surface water total nitrogen trends, total phosphorus showed degrading trends at all York River estuary segments. With respect to bottom waters, degrading trends were observed at all segments except for the lower Pamunkey River which did not exhibit a significant trend. Degrading trends in total nitrogen and phosphorus (1995-2002) were also reported for the Pamunkey River watershed input station (CWVA, 2005).

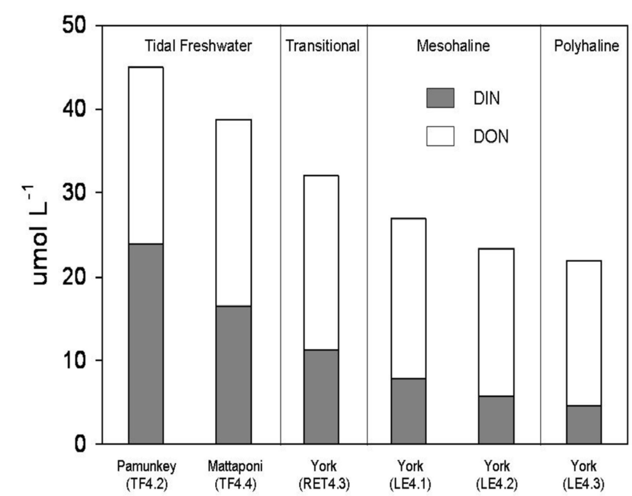

Figure 12. Mean DIN and DON concentrations by York River estuary salinity regimes. Data source: CBP; surface water concentrations from 1997-2006; CBP station identifications are presented in parenthesis.

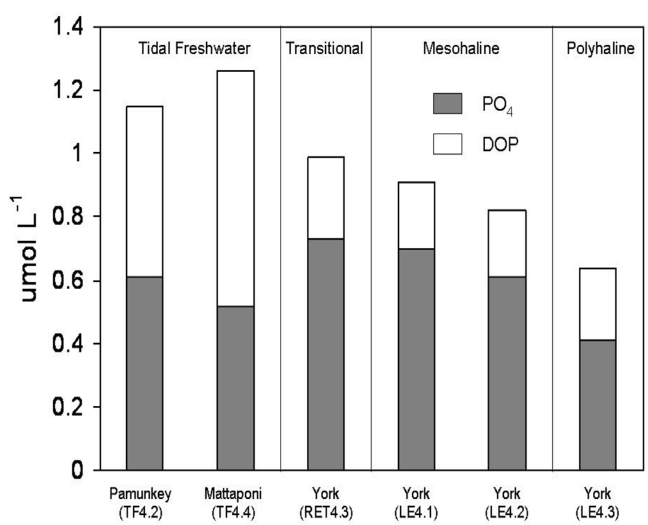

Figure 13. Mean PO_4 and DOP concentrations by York River estuary salinity regimes. Data source: CBP; surface water concentrations from 1997-2006; CBP station identifications are presented in parenthesis.

PRIMARY PRODUCTIVITY AND HARMFUL ALGAL BLOOMS

Diverse ecological and physiographic features of the Chesapeake system, along with variations in chronic and episodic material loadings can result in spatial and temporal variations in phytoplankton biomass, productivity and composition. Despite the complex nature of the Bay system, annual patterns of phytoplankton biomass and productivity are generally recognized. Within the Bay proper, high phytoplankton biomass dominated by diatoms is typically observed in the spring (April-May) in association with high winter-spring riverine nutrient inputs and results in elevated water column productivity (Glibert *et al.*, 1995; Malone *et al.*, 1996; Marshall *et al.*, 2006). Declines in spring phytoplankton biomass are a result of increased nutrient demand coincident with reduced riverine nutrient input (Conley and Malone, 1992; Malone *et al.*, 1996). As the spring phytoplankton bloom settles and accumulates, nutrients are recycled through benthic-pelagic processes to fuel a summer productivity maximum (Kemp and Boynton, 1992 and 1994). Summer composition of phytoplankton is more diverse and includes greater abundance and biomass of chlorophytes and cyanobacteria in the lower salinity regions and dinoflagellates in higher salinity waters (Mallone *et al.*, 1996; Marshall *et al.*, 2006). Phytoplankton biomass and productivity generally decline through the late fall and early winter in association with reduced water temperatures, available nutrients and light.

Analyzing multi-year data, Sin *et al.* (1999) reported repeating patterns of seasonal phytoplankton biomass and productivity that varied between salinity regimes within the York River estuary. In tidal freshwater regions, maximum chlorophyll *a* concentrations (peak monthly mean: 9 μg L^{-1}) generally occurred in the summer and coincided with peak monthly primary productivity on the order of 27 μg C $L^{-1}h^{-1}$. In the transition zone below the freshwater region, which includes the region immediately downriver of the town West Point and the ETM, both a short winter-spring (peak monthly mean: 14 μg L^{-1}) and prolonged summer (peak monthly mean: ~ 18 μg L^{-1}) peak in chlorophyll *a* concentrations were reported. Peak mean monthly primary productivity coincided with periods of elevated chlorophyll *a* concentrations and was on the order of 35 μg and 40 C L^{-1} h^{-1}, respectively. The upper and middle reaches of the mesohaline region exhibited elevated late winter-spring chlorophyll *a* concentrations (peak monthly mean: ~ 25-28 μg L^{-1}) followed by a smaller peak later in the summer (peak monthly mean: ~ 12-14 μg L^{-1}). Sin *et al.* (1999) reported a relatively small late winter-spring chlorophyll *a* concentration peak (peak monthly mean: ~ 15 μg L^{-1}) with no apparent elevated summer values (monthly mean: < 10 μg L^{-1}) in the lower meso-polyhaline region. Primary production within this region showed a spring peak (peak monthly mean: 32 μg C L^{-1} h^{-1}) with relatively high production throughout the summer/fall (mean monthly range: ~15-22 μg C L^{-1} h^{-1}) and in specific winter months. Within the polyhaline region located at the mouth of the York River estuary, seasonal patterns in chlorophyll *a* concentration and productivity were subtle with a minor peak in chlorophyll *a* concentrations of 8-11 μg L^{-1} observed in the late winter-spring and summer with corresponding primary productivity on the order of 22-31μg C L^{-1} h^{-1} (Sin et al., 2006). Mean monthly chlorophyll *a* concentrations for CBNERRVA Reserve components are presented in Figure 14 and follow the temporal patterns as reported by others (Sin *et al.*, 1999, 2006).

Utilizing high resolution temporal dissolved oxygen data from 1995-2000, Sanger *et al*. (2002) estimated gross primary productivity, total respiration and net ecosystem metabolism for the Goodwin Islands and Taskinas Creek Reserve components. Gross primary productivity estimates were 5.15 and 8.88 g O_2 m^{-2} d^{-1}, total respiration was 4.68 and 8.52 g O_2 m^{-2} d^{-1} and net ecosystem metabolism was 0.48 and -2.07 g O_2 m^{-2} d^{-1}, for Goodwin Islands and Taskinas Creek, respectively. Estimates of net community metabolism indicate Taskinas Creek is a heterotrophic site as compared to Goodwin Island which is autotrophic, one of the few in the National Estuarine Research Reserve System. It should be noted that the location of the Goodwin Island monitoring station is located within SAV beds and Taskinas Creek drains a nontidal forested wetland and tidal marsh system.

By affecting residence time, nutrient input, light regime and tidal mixing, river discharge is a controlling factor that regulates temporal and spatial phytoplankton dynamics within the York River estuary (Sin *et al.*, 1999). A negative correlation between chlorophyll *a* levels and river discharge in the tidal freshwater region suggests that winter or high flow periods flush this region at a sufficient rate to prevent accumulation of phytoplankton biomass. In the more downriver mesohaline reaches, a positive correlation suggests that high riverine input stimulates growth and may determine location, magnitude and timing of winter-spring bloom. Investigating phytoplankton assemblages in the York River estuary, Marshall and Alden (1990) report bidirectional transport of phytoplankton with short-lived to moderately tolerant freshwater species moving downstream and estuarine Bay species moving upstream throughout the year in sub-pycnocline waters.

Based on long-term data analyses, field and modeling studies (Sin and Wetzel, 2002a, 2002b; Sin *et al.*, 2006), phytoplankton dynamics in the lower mesohaline region of

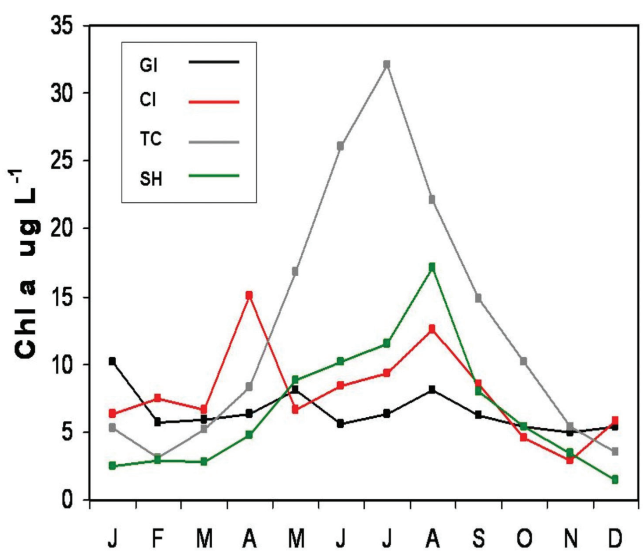

Figure 14. Seasonal chlorophyll *a* concentrations for Reserve components. GI: Goodwin Islands, CI: Catlett Islands, TC: Taskinas Creek and SH: Sweet Hall Marsh. Data sources: NOAA/NERRS SWMP monthly sampling program: 2002-2006.

the York River estuary are regulated by abiotic mechanisms (bottom-up control) such as nutrient supply rather than biotic mechanisms (top-down control) such as zooplankton grazing. The availability of nutrients and light are governing factors affecting phytoplankton growth rates and production. Based on DIN:DIP molar ratios (16:1), Sin (1999) suggested potential year-round phosphorus limitation for all seasons in tidal freshwater regions, shifting to potential nitrogen limitation during the summer-fall period in the oligohaline transitional zone, and potential nitrogen limitation within the mid and lower mesohaline regions throughout the year except during periods of peak river discharge. Nutrient enrichment studies by Webb (1987) also indicated seasonal nutrient limitation patterns in the lower York River with phosphorus limitation in the late fall and spring and nitrogen limitation during late spring and summer. DIN:PO_4 ratios for Reserve components are presented in Figure 15. While all Reserve components exhibited DIN:PO_4 ratios indicative of both potential nitrogen and phosphorus limitation, values associated with Sweet Hall Marsh (located in the lower tidal freshwater-oligohaline region of the Pamunkey River) were elevated suggesting a greater degree for potential phosphorus limitation than other Reserve components.

A Phytoplankton Index of Biotic Integrity (PIBI) has been developed for Chesapeake Bay to assess phytoplankton health with respect to "reference communities" found in desirable water quality conditions (Buchanan *et al.*, 2005). Utilizing data from 1985-2002, PIBI scores of CBP monitoring stations for the tidal freshwaters of the Pamunkey River indicate poor to fair status in the spring and fair to good status in the summer while the upper mesohaline reach of the York River indicates a poor-fair status in the spring and a poor status in the summer (Lacouture *et al.*, 2006). Waters in the open Mobjack Bay complex exhibit a poor-fair status for both spring and summer. Phytoplankton features in waters with a fair-poor

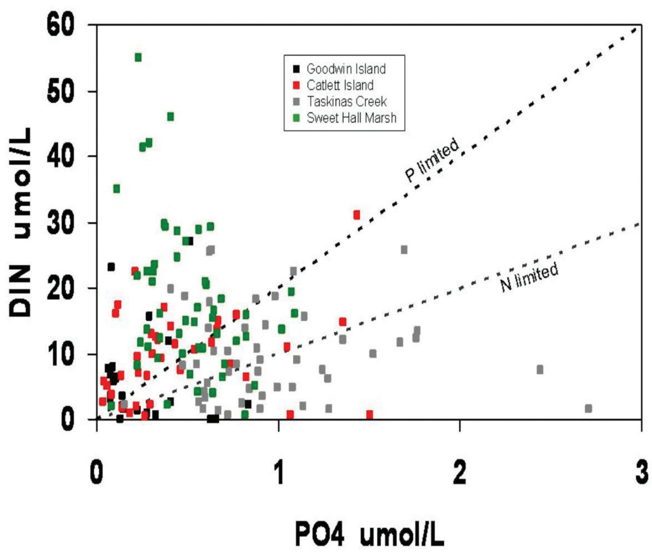

Figure 15. Water column DIN:PO_4 ratios for Reserve components. Dashed lines depict ratios of 10 and 20; ratios <10 indicate N limitation and >20 indicates P limitation (Boynton *et al.*, 1982). Data source: NOAA/NERRS SWMP monthly sampling program for the period 2002-2006; samples below detection limits were not included in analysis.

status include frequent algal blooms and somewhat frequent HABs, high variability in biomass and species composition, and exceedance of water quality criteria (Buchanan, 2006).

When in low concentrations, phytoplankton and cyanobacteria generally pose no environmental or human health issues. However under certain environmental conditions, these organisms can proliferate to such a degree as to cause deleterious effects through the production of toxins or by their accumulated biomass which can affect water clarity, oxygen dynamics, and food-web dynamics. It is generally recognized that degraded water quality from increased nutrient enrichment promotes the development and persistence of many harmful algal blooms (HABs); that both the total quantity and composition of the nutrient pool impacts HABs; that externally derived nutrients are required to sustain HABs; and both chronic and episodic delivery of nutrients can promote HAB development (GEOHAB, 2006). In addition to enhanced material loadings, particularly nutrient enrichment, physical forcings such as river inflow, circulation and vertical mixing play an important role in the development, extent and persistence of HABs (Sellner *et al.*, 2003; GEOHAB, 2006). There have been a number of reported sporadic and reoccurring HABs within the York River estuary. The bloom producing dinoflagelletes, *Cochlodinium polykrikoides*, C. *heterolobatum* and *Prorocentrum minimum*, are associated with the "red tide" that generally occurs on an annual basis in summer months in the lower York River (Ho and Zubkoff, 1979; Marshall, 1994) (Figure 16). In the spring of 2005, relatively high concentrations (177 and 505 cells mL^{-1}) of the dinoflagellate *Pfiesteria shumwayae* were reported at the Taskinas Creek component of the Reserve (VDH, 2005). The cyanobacteria *Microcystis aeruginosa* is relatively common in the York River and has been implicated in blooms within the Chesapeake Bay (Gallegros and Jordan, 2002).

Hypoxia, or depletion of oxygen to a defined lower limit, and anoxia, the complete lack of oxygen, has been a recurring condition within bottom waters of the Chesapeake Bay proper and some of its tidal tributaries (Smith *et al.*, 1992). Within the York River estuary, hypoxia has been observed repeatedly in the bottom waters of its lower reaches when water temperatures exceed above 20°C (Kuo and Neilson, 1987). In this

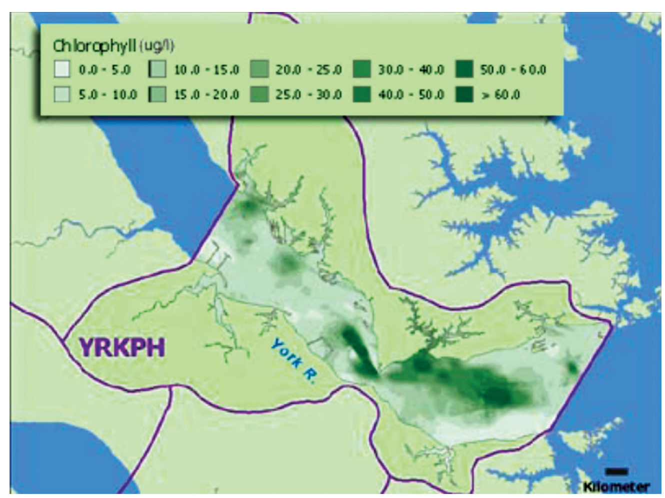

Figure 16. Surface chlorophyll *a* concentrations during "red tide" event in the lower York River (Sept. 9, 2007). Data and map source: Virginia Estuarine and Coastal Observing System, www.vecos.org.

study, hypoxia, defined as < 50% of dissolved oxygen summer saturation values, occurred in 50 % of the York River surveys over a 15 year period. Based on 1997-2006 CBP data for bottom waters in the lower York River (station: LE4.2), average summer dissolved oxygen levels are 4.1 mg L^{-1} (range: 1.1 to 7.3), compared to 8.5 mg L^{-1} (range: 3.7-12.5) for spring, 5.9 mg L^{-1} (range: 3.4-9.1) for fall and 10.1 mg L^{-1} (range: 7.4-13.4) for winter months. Oxidation of organic matter and sediment oxygen demand are important dissolved oxygen sinks while vertical diffusion transport and longitudinal advective transport due gravitational circulation are thought to be primary controlling factors replenishing the supply of oxygen to deep waters (Kuo and Neilson, 1987). With respect to status and trends of bottom waters within the York River estuary, dissolved oxygen level status (2002-2004) was fair to good and there were no significant degrading or improving trends (1985-2004) in all segments of the estuary (Dauer, 2005).

In addition to depletion of oxygen in channel bottom waters, diel variations in dissolved oxygen concentration in shallow waters can be significant and result in low dissolved oxygen conditions. This phenomenon is often observed in temperate unstratified shallow habitats where nighttime respiration temporarily deplete water oxygen levels which are subsequently replenished by photosynthesis during day-time conditions. Investigating dissolved oxygen dynamics at the national reserve-wide scale, Wenner *et al*. (2001) did report hypoxic water conditions, however at a very low percent level, for the Taskinas Creek component of the Reserve.

TOXIC CHEMICALS

Chemical contaminants entering the Bay and its tidal tributaries come from a variety of natural processes, such as weathering of rocks, and human derived point and nonpoint sources. Toxicity of a chemical depends on a multitude of factors, including the chemical and physical properties of the contaminant (e.g. concentration, form of speciation, persistence), the receiving water body and the living resources of interest. Priority toxic contaminants identified by the CBP include polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), organochlorine and organophosphate pesticides, and “other” priority pollutants such as metals (USEPA, 2006). These toxic compounds are known or suspected carcinogens (PAHs, PCBs, organochlorine pesticides), cause neurological damage (PCBs, mercury, organochlorine and organophosphate pesticides) and other adverse health conditions. While there appears to be areas of limited toxic chemical contamination and associated adverse effects, broad-scale degradation of the York River estuary due to toxicological stressors is not apparent.

There have been a limited number of studies that have focused on ambient water column and sediment toxic chemical testing in the York River estuary. Hall *et al.* (1998) monitored water toxicity in the mouth of the Pamunkey River, adjacent to the town of West Point and location of potential industrial contaminant sources, in 1995 and reported concentrations of organochlorine pesticides that were below levels that cause adverse effects and elevated lead concentrations that exceeded USEPA chronic water quality criteria. Aqueous and sediment toxicity was not observed during this study. McGee *et al.* (2001) monitored sediment toxicity in both the Mattaponi and Pamunkey Rivers adjacent to and downstream of the town of West Point and reported no contaminant concentrations of concerns and found little to no sediment toxicity. Wright *et al.* (2002) evaluated a number of sites on the Mattaponi and Pamunkey Rivers in 2000-2001 with respect to aqueous and sediment chemical analysis and sediment toxicity. With the exception of the metal manganese (Mn), most sediment contaminant (PAHs, selected chlorinated pesticides, selected metals) concentrations were low or below detection levels. Selected pesticides, in particular atrazine and metalochlor, were detected in water samples during this study.

As part of VaDEQ’s Fish Tissue and Sediment Monitoring Program, sediment metal and PAH concentrations are measured within the Mattaponi and Pamunkey River systems. As summarized by Roberts *et al.* (2004) for the period 1997-2000, the sediment quality guideline Effects Range - Low (ERL; adverse effects on organisms are rarely observed when concentrations fall below the ERL value.) was exceeded at selected stations for the metals Chromium, Nickel, Mercury and Zinc; no exceedances for metals were observed for stations located in the Mattaponi River. With total low and high molecular weight PAHs concentrations ranging from 6.2-218.6 and 59.6-1210.5 ng g^{-1} dry weight, respectively, no exceedances of PAH sediment quality guidelines were observed in either river. The most extensive study to characterize the chemistry, toxicology and biological community of the sediments within the tidal reaches of the Mattaponi and Pamunkey Rivers was conducted by Roberts *et al.* (2004). Reported sediment low molecular PAHs concentrations did not exceed detectable limits, high molecular PAHs concentrations were low and did not exceed ERL guidelines, and exceedances of ERL guidelines for the 16 tested metals were relatively infrequent and included Arsenic (range: detection limit to 10.2 μg g^{-1}), Chromium (range: 6-47.7μg g^{-1}), Zinc (range: 22.2-163 μg g^{-1}), and Manganese (range: 136-3,380 μg g^{-1}). Selected organophosphate and organochloride pesticides were detected in both aqueous and sediment samples at relatively low levels and selected herbicides were below detection for all samples. Sediment toxicity tests of three invertebrate species showed no significant impacts.

A recent report by Hartwell and Hameedi (2007) summarizes the results of NOAA’s Chesapeake Bay-wide sediment chemistry, toxicity and benthic community studies. The study reported mean Effects Range - Median quotient (ERMq; contaminant concentrations equal to or exceeding ERM levels would frequently result in adverse effects on organisms) levels of <0.1 and 0.1 to 0.2 for York River stations; the calculation included low and high molecular weight PAHs, total PCBs, total DDT, and individual metals except for Nickel. For comparison purposes, mean ERMq levels within the Chesapeake Bay and its tributaries varied from 0.0 to 0.72 with contaminated sites such as Baltimore Harbor and the Elizabeth River exhibiting ERMq levels on the order of 0.5. In the southeast US, a mean ERMq value of 0.1 is generally considered the threshold where degradation of benthic communities can begin to be observed (Hyland *et al.*, 1999). Results of York River toxicity tests reported in the NOAA study were mixed, showing no significant difference in amphipod survival responses in whole sediment bioassays at all stations, both significant and no significant differences in sea urchin fertilization bioassay responses in sediment pore water, and low (≤10 B[a]P equivalents) human reporter gene system cytochrome P450 bioassays responses at all stations.

Investigating PAH distribution and association with organic matter in surface waters of the York River estuary, Countway *et al.* (2003) classified PAHs into three groups (e.g., volatile, soot-associated and perylene) and suggested processes controlling their delivery to the estuary. The more volatile PAHs enter through gas exchange across the air-sea interface with subsequent partitioning by phytoplanton; soot-associated PAHs were primarily (~75%) coal derived and enter through watershed runoff of soot particulate matter; and the source of perylene is terrestrial and/or a product of diagenetic processes in soil and/or marshes.

Specific contaminants can bioaccumulate in fish tissue at levels that warrant consumption advisory in order to protect human health. Contaminants listed in fish consumption advisories in Virginia coastal waters include polychlorinated biphenyls (PCBs), mercury and Kepone (VaDEQ, 2006). Specific to the York River basin, mercury and PCB fish consumption advisories and restrictions were issued by the Virginia Department of Health in 2004 and are currently in effect (VaDH; Figure 17). As with other principal tributaries (i.e. James and Rappahannock Rivers) within the southern Chesapeake Bay region, a PCB fish consumption advisory exists for the entire York River estuary below the confluence of the Mattaponi and Pamunkey Rivers. The upper tidal regions of the Mattaponi and Pamunkey Rivers, which receive significant wetland drainage, exhibit environmental conditions (e.g., low pH, low dissolved oxygen levels, and high organic matter) that have been recognized as being associated with increased potential for bioaccumulation of mercury in fish (see reviews by Ullrich *et al.*, 2001 and Ravichandran, 2004). Additional mercury fish consumption advisories, including the Dragon Run Swamp/Upper Piankatank River, and the Dismal Swamp canal and Blackwater and Nottoway Rivers within the Chowan River basin, occur within coastal water bodies associated with large swamp and wetland systems with little or no industrial or municipal dischargers.

PCBs are a class of organic chemical compounds that were used extensively in industrial manufacturing (e.g., production of dielectric fluids for transformers and capacitors, synthetic resins and epoxy paints) and exhibit a high degree of resistance to degradation processes. Given that production of PCBs ceased in 1977, PCBs are currently released into the environment from hazardous waste sites, illegal/improper discarding of PCB-containing wastes, atmospheric deposition or from failing PCB-containing equipment. Large-scale soil PCB removal actions have occurred at federal (Yorktown Naval Weapons Station and Camp Peary immediately adjacent to the York River in James City County) and superfund (H&H burn pit site in Hanover County) facilities within the York River basin (VaDEQ, 2005). Being only slightly soluble in water, PCBs accumulate in soil where they can enter waterbodies through runoff processes and persist in sediments for many years and enter the foodchain. Reported PCB sediment concentration ranges within the Pamunkey River are 0.0-2.3 ppb (dry weight basis), 0.0- 0.76 ppb in the Mattaponi River and 1.2-5.3 ppb in the York River proper. Creeks draining into the York River exhibited elevated sediment levels of 25.6 ppb for Felgates Creek and 63.5 ppb for King Creek (PCB ERL = 22.7 ppb; VaDEQ 1995-2002 PCB sediment database).

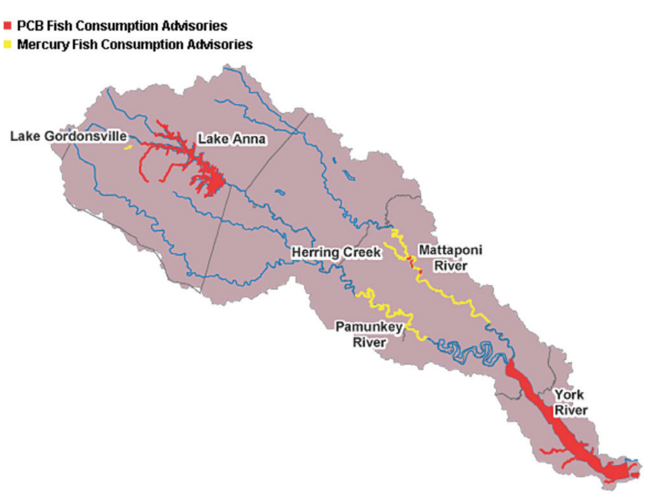

Figure 17. Current PCB and mercury fish consumption advisories within the York River watershed and estuary. Image source: VA Department of Health.

In contrast to PCBs, mercury is released to the environment by both natural processes and human induced activities. Model simulations suggest that atmosphere deposition is a primary source of mercury to the Chesapeake Bay system (Mason *et al.*, 1997); dominant emission sources within the Bay region include coal fired electrical generation and waste incineration plants. Regional weekly total mercury wetfall concentrations, for the time period (12/2004-4/2007) ranged from 0.9 to 40.4 ng L^{-1} and deposition rates varied from 3.9 to 1697.4 ng m^{-2} (NADP/MDN, Station ID VA(98); estimates of weekly dryfall are on the order of 1080 ng m^{-2}. Atmospheric mercury exists in three primary forms, gaseous elemental mercury, reactive gaseous mercury and fine particulate bound mercury. One of the key factors that can influence the bioaccumulation of mercury is its conversion to methyl-mercury (CH_3Hg^+) via microbial mediated pathways. Once in the methyl-mercury form it is readily assimilated into higher trophic levels. Reported mercury sediment concentration ranges within the Pamunkey River are 0.03-0.57 ppm (dry weight basis), <0.01- 0.32 ppm in the Mattaponi River and 0.11-0.22 ppm in the York River proper. Creeks draining into the York River exhibited elevated sediment levels of 0.15 ppm for Felgates Creek and 0.19 ppm for King Creek (PCB ERL = 0.15 ppm; VaDEQ 1995-2002 metals sediment database).

MICROBIAL PATHOGENS

The existence of pathogens has been the most cited water quality problem associated with nonpoint sources of pollution in Virginia (VaDEQ, 2004). Due to the presence of pathogenic bacteria and viruses, fecal contamination of water used for domestic, commercial, recreational purposes is regarded as a health hazard. Examples of human health hazards include the waterborne diseases of dysentery, viral and bacterial gastroenteritis, typhoid fever and hepatitis A. Sources of fecal indicator pathogens include nonpoint source runoff from urbanized, agricultural and natural lands, failing residential on-site septic systems and municipal wastewater treatment facilities, combined sewer and stormwater runoff systems, industrial point sources such as paper mill effluent, and direct domestic and wild animal loadings. A GIS-based analysis of fecal coliform bacteria levels within Virginia's coastal waters identified several significant trends that included elevated concentrations in the summer versus winter, consistently higher fecal coliform bacteria concentrations with distance upstream in tidal creeks and embayments, and elevated concentrations after period of high rainfall (Shima *et al*., 1994).

In order for the Commonwealth's shellfish industry to engage in interstate commerce, shellfish waters are classified using the requirements and standards of the National Shellfish Sanitation Program (NSSP). Virginia's Department of Health (VaDH)/Division of Shellfish Sanitation classification of shellfish water is a multi-step process that includes shoreline surveys to identify actual and potential sources of pollution and fecal coliform bacteria monitoring of growing waters. Fecal coliform organisms are used as an indicator of fecal pollution from warm blooded animals. The national standard for shellfish waters is a geometric mean of 30 samples not to exceed 14 fecal coliforms 100 mL^{-1} of seawater (USFDA, 2003). Additionally, the standard requires that the estimated ninetieth percentile not exceed 49 fecal coliforms 100 mL^{-1}. With respect to primary contact recreation protection, the standard is commonly set at 200 fecal coliforms 100 mL^{-1} (VaSWCB, 2007).

Of the 158 km^2 of assessed shellfish waters within the York River estuary, 20 percent (31.1 km^2) was impaired with respect to meeting the fecal coliform pathogen indicator standard (VaDEQ/VaDCR, 2006). With exception of the upper portion of the York River (including lower portions of the Mattaponi and Pamunkey Rivers) in the vicinity of the town of West Point, and the nearshore vicinity around the Naval Weapons Station, Cheatham Annex and the Yorktown Refinery, condemned shellfish grounds are restricted to smaller tidal creek systems draining into the York River proper (Figure 18). Condemened creeks in close association with Reserve components include Taskinas Creek, Timberneck and Cedarbush Creek (Catlett Islands), and Back Creek (Goodwin Islands). Concentrations generally increase with distance up the creeks where flushing rates may be reduced, suspended solids increase and the ratio of shoreline to water volume ("land effect") increases. Using Timberneck Creek as an example, the geometric mean of fecal coliform concentrations increase from 4.5 per 100 mL (90^{th} percentile: 14.5), to 10.3 per 100 mL (90^{th} percentile: 62.1) 0.5 km upstream to 24.9 per 100 mL (90^{th} percentile: 108.6) one km upstream.

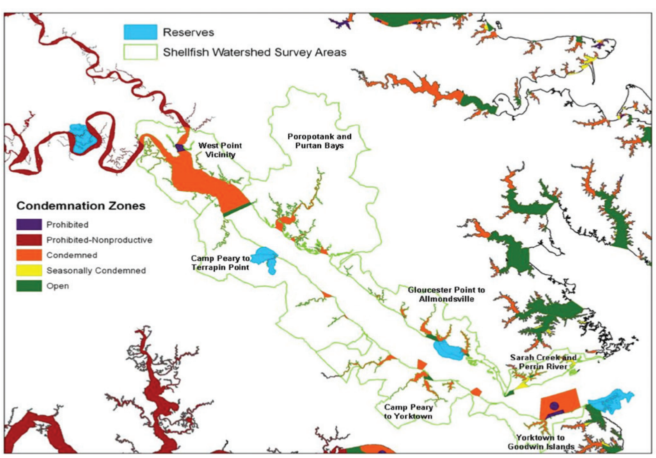

Figure 18. Current shellfish prohibited and condemned growing areas within the York River estuary. Data source: VA Department of Health (2007).

Potential sources of fecal pollution vary between Reserve components; a summary review of VaDH Shoreline Surveys results within Reserve boundaries or immediately adjacent creeks/upland areas are presented in Table 2. Common to the Goodwin Island, Catlett Island and Taskinas Creek components of the Reserve were facilities that provide various boat mooring slips and/or marine services. In addition, it should be assumed that wildlife contributions may be a significant fecal coliform source at all Reserve components; wildlife sources of fecal contamination have been documented at Taskinas Creek (Kator

Table 2. *Summary of potential fecal pollution sources based on VaDH Shoreline Surveys for Goodwin Islands (Area: #52, 2004-2005; #53, 2001-2002), Catlett Islands (Area: #47, 2004) and Taskinas Creek (Area: #50, 2005-2006). Direct contributions are presented with indirect contributions presented parenthetically.*

Pollution Category	Goodwin Islands	Catlett Islands	Taskinas Creek
Sewage Pollution Sources			
Sewage treatment facilities	1 (0)	0 (0)	0 (0)
On-site sewage deficiencies	0 (0)	0 (8)	0 (0)
Potential pollution	1	5	0
Non-Sewage Waste Sites			
Industrial waste sites	0 (3)	0 (0)	0 (0)
Solid waste dumpsites	0 (1)	0 (0)	0 (0)
Boating Activity			
Marinas	0	0	0
Other boat moorings	4	2	1
Domestic Animal Pollution	0 (0)	0 (1)	0 (5)

and Rhodes, 1999). Shoreline surveys within the immediate area of Goodwin Islands (Back Creek and lower end of Goodwin Neck) identified a number of potential sources including direct inflows from the York River sewage treatment plant operated by Hampton Roads Sanitation Districts. Two industrial sources that previously contributed processing wastes directly to Back Creek have subsequently been connected to the central HRSD system as are expected most residential areas. Local pollution sources potentially impacting Catlett Island (i.e., Timberneck, Poplar and Cedarbush Creeks) are dominated by observed failings of residential on-site wastewater disposal system (OSWDS; septic tanks and associated leach fields); past direct domestic livestock contributions were removed in 2005.

LARGE STORM IMPACTS

Historically, the impact and frequency of large-scale storms (e.g., tropical cyclones and nor'easters) have varied in the Chesapeake Bay region and more specifically in the York River system (Figure 19). Concern over large-scale storms is increasing given sea-level rise and climate change implications; the number of North Atlantic hurricanes are projected to increase over the next few decades (Goldenberg *et al.*, 2001). Large-scale storms generate both short and longer-term dis-

Figure 19. Nearshore impact at Gloucester Point, VA. from tropical depression Ernesto (9/1/2006). Photo courtesy of W. Reay.

turbances in response to high winds, storm surges and rainfall. Consequences of storm surges and surface waves include extensive flooding of low-lying areas, shoreline erosion, sediment resuspension and associated pollutant availability, vertical column mixing and increased upstream salinities (Walker, 2001). Consequences of excessive rainfall include elevated direct and watershed runoff freshwater input and associated downstream salinity depression (Peierls *et al.*, 2003; Bales, 2003), along with elevated material (e.g., sediment, carbon, nutrients) loadings from stormwater runoff (Walker, 2001; Paerl *et al.*, 2001; Mallin *et al.*, 2002; Bales, 2003; Burkholder *et al.*, 2004). Just as each storm has distinct characteristics and hydrologic responses by the impacted watershed and water body, the type and severity of ecosystem responses can also vary. Reported responses by estuarine systems include elevated phytoplankton biomass and changes in community composition stimulated by newly available nutrients (Peierls *et al.*, 2003), depressed oxygen levels and severe hypoxic events (Paerl *et al.*, 2001, 2003; Burkholder *et al.*, 2004) and damage to vegetative communities (Valiela *et al.*, 1998).

Two of the most studied large-scale storms within the Chesapeake Bay region include Tropical Storm Agnes in June 1972 (Davis *et al.*, 1976) and Isabel which made landfall September 18, 2003 (Sellner, 2005). Focus will be given to Tropical Storm Isabel due to the availability of York River water quality related information. The hydrodynamic response of the York River estuary to Isabel has been reported on by a number of investigators (Reay and Moore, 2005; Brasseur *et al.*, 2005; Gong *et al.*, 2007). Regional rainfall from September 18-19, 2003, ranged from 5.8-11.7 cm. Peak mean daily streamflow occurred on September 21, 2003 and represented a 20 and 30 fold increase over pre-storm conditions on the Mattaponi and Pamunkey Rivers, respectively. Isabel produced a storm surge of 1.7 m near the mouth of the York River estuary and 2.0 m in the upper tidal freshwater regions. Maximum wave height ($H_{1/10}$) was on the order of 2.0 m and maximum water velocity was 1.0 m sec^{-1} at the surface and 1.6 m sec^{-1} at depth (4 m). Net salt flux into the York River estuary increased by a factor of 30 during the storm surge and resulted in a short-term pulse of high salinity water; approximately 10 ppt greater than pre-storm conditions within the oligohaline portion of the estuary (see Figure 4). In comparison, salinity levels in the upper tidal freshwater regions and the downriver meso and polyhaline regions remained relatively unchanged. Following the storm surge, salinity levels within the lower portions of the York River estuary declined 1.5 to 4.5 ppt for an extended period in response to freshwater input. The high freshwater input changed the York River estuary from a partially mixed estuary to a very stratified estuary for a prolonged period of time.

Decreased water clarity, as measured by increased turbidity, was observed throughout the York River estuary during and after Isabel's passage. Contributing factors that led to elevated, and in some case extreme, turbidity levels included shoreline erosion and sediment resuspension caused by currents and waves during the storm surge, and subsequent watershed runoff. During the storm, acoustic Doppler current profiler (ADCP) backscatter, which can serve as a qualitative measure of suspended solids, was elevated and uniform with depth indicating elevated sediment load and complete water column (water depth range: 8-10 m) mixing during the storm and into the following day at Gloucester Point (Brasseur *et al.*, 2005). It took at least one-week for surface backscatter signals to return to pre-storm levels. With regards to shallow waters, maximum storm surge associated turbidity levels varied between 192 and > 1000 NTUs; pre-storm turbidity levels were 10-15 NTUs within the tidal freshwater and polyhaline regions and 50-100 NTUs at upper meso haline and lower oligohaline regions (Reay and Moore, 2005). The duration of highly turbid water (≥ 200 NTUs) in shallow shoal waters was relatively short-lived, returning to pre-storm or near pre-storm conditions within 24-30 hrs at the oligo through polyhaline stations. Moderately elevated turbidity levels persisted for several days at the tidal freshwater stations due to freshwater inflow and associated runoff.

A gradual increase (1-2 mg L^{-1}) in dissolved oxygen was observed immediately prior to and during the storm tide at shallow water tidal freshwater and oligohaline station likely in response to enhanced mixing and agitation from wind, waves, current and influx of higher salinity water (Reay and Moore, 2005). This pattern was not evident at higher salinity stations where daily maximum oxygen levels were already at or near saturation levels as compared to tidal freshwater and oligohaline stations. As the storm tide ebbed, dissolved oxygen returned to pre-storm conditions at shallow water oligohaline stations but continued to recede, resulting in mean daily concentrations of 3-4 mg L^{-1}, in the tidal freshwater regions and taking an additional two-weeks to return to pre-storm conditions (Figure 20). Enhanced watershed material loadings, in particular degradable organic matter, are implicated in being a controlling factor in the development and sustaining reduced oxygen levels within these regions. Inadequate data was available to assess dissolved oxygen dynamics in deep channel waters of the York River. CBP monitoring data collected prior to Isabel's passage showed dissolved oxygen concentration of 4.7 mg L^{-1} (date: 9/16/2003) and 5.1 mg L^{-1} on subsequent sampling (10/7/2003) near Gloucester Point (station ID: LE4.2). In contrast to other regions of the Bay, no apparent increases in phytoplankton biomass was observed post-Isabel in the York River. Miller *et al.*, (2005) reported significant phytoplankton biomass increases in the mid-lower Chesapeake Bay following the passage of Isabel. The inves-

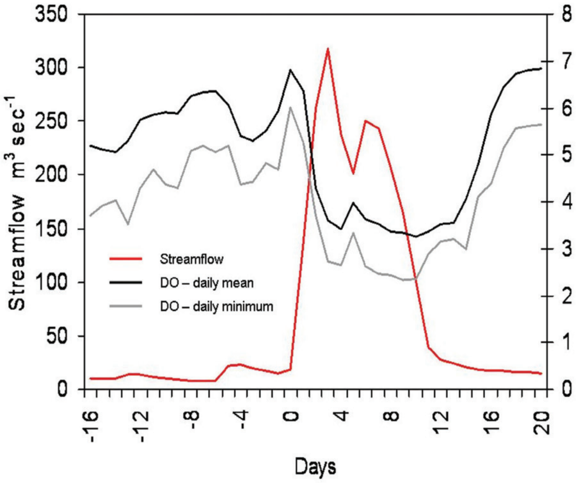

Figure 20. Daily mean and minimum dissolved oxygen concentrations at White House, located in the upper tidal freshwater regions of the Pamunkey River, prior to, during and post Isabel. Streamflow is from Hanover located above tidal influence. Figure from Reay and Moore, 2005.

tigators suggested that storm surge and wind mixing introduced bottom water nutrients into the photic layer during a period of nitrogen limitation as the likely physical mechanism responsible for enhanced phytoplankton biomass. It should be noted that the passage of Tropical Storm Isabel occurred following historic wet conditions within the Bay region.

FUTURE RESEARCH NEEDS

While significant effort has focused on water quality aspects of the York River estuary, there remains a number of research and monitoring priority areas that would enhance our basic understanding of estuarine processes and support tributary management strategies. Essential to York River water quality management strategies is a better understanding of material flux into and out of the riverine system. Specific to nutrients and contaminants (e.g., PCBs, PAHs and Hg), additional information is needed with respect to groundwater and atmospheric loadings, and Bay/oceanic flux occurring at the mouth of the York River estuary. Studies should be conducted to address the impacts of landscape management as related to increasing watershed population, changing landscapes, sea level rise and climate change, and episodic events (e.g., large-scale storms, droughts) on watershed processes and material loadings to tidal waters. Additional studies are needed to source track pathogenic microbes and investigate the role of estuarine substrates with respect to microbe survival and sediment resuspension with respect to water quality and shellfish growing bed closures. As well as watershed processes, additional efforts should refine the description of physical estuarine processes, such as circulation patterns, mixing processes, residence time and exchange of water between shallow shoal and deeper channel regions and their impacts water quality.

Further studies are needed regarding interrelationships between ecosystem response and water quality and physical factors within various salinity regimes. Of prime importance is ecosystem response to temporal and spatial variations in nutrient (i.e., N, P and Si) and sediment inputs. In addition to general phytoplankton dynamics, a greater understanding of the linkages of water quality to the development and sustenance of HABs is warranted. Determination of the spatial and temporal extent of hypoxic and anoxic conditions within the York River proper, its principal tributaries and of smaller sub-tributaries would greatly support tributary management and habitat restoration efforts within the York River system. In addition to focusing on degrading water quality, efforts should also focus on ecosystem (i.e., benthic, nekton and plankton) response to improving water quality conditions. Maintenance and enhancement of long-term monitoring programs would also support resource management and scientific community. In addition to current efforts that support regulatory programs and physical modeling efforts, build-out or technological advances of the monitoring program could lead to forecast ability with respect to HABs and low DO events.

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York River Tidal Marshes

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ABSTRACT

The York River has nine tidal wetland community types that are distributed along gradients of salinity and tidal inundation. These range from the Saltmarsh Cordgrass community dominated by *Spartina alterniflora* to the Tidal Freshwater Mixed community that can have over 50 species in one marsh. These tidal marshes provide a number of important functions and values to the estuarine systems including: high primary productivity, important habitat value, erosion buffering and filtering capacity useful for trapping sediments, pollutants and nutrients. The tidal marsh communities within the four Chesapeake Bay Virginia National Estuarine Research Reserve sites are situated along the York system in polyhaline, mesohaline, oligohaline and freshwater salinity regimes. They are largely pristine vegetation communities and have been documented to have abundant fauna characteristic of their individual community types. Changes in the vegetation communities of each site have been documented over time; however more research is needed on the potential effects of projected sea level rise on these habitats and the roles of watershed sedimentation and nutrient enrichment, vegetation succession, and invasive species on the persistence and value of these tidal marsh areas.

INTRODUCTION TO TIDAL MARSHES OF THE YORK RIVER

The York River has a large number of wetland communities that are distributed along gradients of salinity and tidal inundation (Wass and Wright, 1969, Perry and Atkinson, 1997). The vegetation communities in these wetlands depend on a wetlands location along these gradients (Odum *et al.*, 1984, Odum, 1988, Perry and Atkinson, 1997). In turn, tidal and salinity gradients can vary both spatially and temporally (Odum *et al.*, 1984, Hull and Titus, 1986, Odum, 1988).

The combined stress of inundation and salt water, while limiting the types of biota that can survive in the marshes of the lower portion of the bay, also provide for a diverse number of tidal wetland habitats. In upstream reaches the water column salinity is low to non-existent. Without the stress of salinity, more species of vascular plants are able to survive (Anderson *et al.*, 1968, Wass and Wright, 1969, Odum *et al.*, 1984, Perry and Atkinson, 1997). In these tidal fresh water zones, over 50 species ha^{-1} may be common (Doumlele, 1981, Odum *et al.*, 1984, Odum, 1988, Perry and Atkinson, 1997, Perry and Hershner, 1999). Here tidal inundation can be the principal factor affecting community composition and function. In the lower portion of the river only a few vascular plants are able to tolerate the combined effects of tidal inundation and high salt content of the water. For a comprehensive comparison of tidal salt marshes and freshwater marshes of Chesapeake Bay see Odum (1988).

The tidal wetlands of the Chesapeake Bay perform a number of important ecological functions that are attributed high value by humans. The most important of these functions and values are primary production and detritus availability, wildlife and waterfowl support, shoreline erosion buffering, and water quality control.

Primary productivity in tidal marshes can reach 4 metric ton $ha^{-1}\,y^{-1}$, with an average range of 0.4-2.4 metric ton $ha^{-1}\,y^{-1}$. This high level of primary productivity results in a high level of detritus production, which is the basis of a major marine food pathway, which includes crabs, other shellfish, and finfish. In addition to providing food, tidal marshes provide spawning and nursery habitat. It has been estimated that 95% of Virginia's annual harvest of fish (commercial and sport) from tidal waters is dependent to some degree on wetlands (Wass and Wright, 1969). Some of the important wetland-dependent fisheries in the Chesapeake Bay include blue crabs, oysters, clams, striped bass, spot, croaker, and menhaden.

The Chesapeake Bay is home to approximately 1 million waterfowl each winter. The ducks and geese benefit both directly and indirectly from the productivity and habitat provided by the Bay's marshes. Marsh-nesting birds include Virginia and clapper rails, mallard and black ducks, willet, marsh wren, seaside sparrow, red-winged blackbird, boat-tailed grackle, and northern harrier (Watts, 1992). Chesapeake Bay marshes are also used by herons and egrets year-round, and by transient shorebirds such as yellowlegs, semi-palmated sandpiper, least sandpiper, dowitcher, dunlin, and sharp-tailed sparrow (Watts, 1992). Muskrats are the most visible marsh-dependent mammals.

Tidal marshes dissipate incoming wave energy, thereby providing a buffer against shoreline erosion. Knutson *et al.*, (1982), studying *Spartina alterniflora* marshes in the Chesapeake Bay, found that over 50% of wave energy was dissipated within the first 2.5 meters of the marshes. Rosen (1980) found that marsh margins form the least erodible shorelines.

Marshes in the Chesapeake Bay play a very important role in maintaining and improving water quality by trapping sediment from upland runoff and from the water column, thereby reducing siltation of shellfish beds, submerged aquatic vegetation beds, and navigation channels. Pollutants may also be filtered from runoff and the water column, and taken up by marsh plants.

Over one half of all Virginians live on the coastal plain that makes up a little under a third of the state's landmass (Colgan, 1990, Mason, 1993). This population pressure has resulted in increased impacts to salt marshes. Wetlands Watch, a Virginia NGO, has estimated that Virginia could lose between 50% and 80% of its remaining vegetated tidal wetlands by the year 2107 due to sea level rise (www.wetlandswatch.org, 2007). As sea level rises, homeowners will want to harden their shores to protect against property loss. This hardening may stop any shoreward progression of tidal marshes and more than likely increase tidal marsh losses.

DISTRIBUTION AND BIOTA OF YORK RIVER MARSHES

Nine common vegetated marsh types have been described in the tidal freshwater, oligohaline, mesohaline, and polyhaline sections of the York River (VMRC 1980, Perry *et al.*, 2001). These are arranged in the York River landscape along a salinity gradient with the polyhaline marshes at the mouth and tidal freshwater marshes further upstream from the saltwater influence (Wass and Wright, 1969, Odum *et al.*,1984, Perry and Atkinson, 1997).

All of the marshes within the CBNERRVA are high in biomass productivity and are important as wildlife, finfish, and shellfish habitat. A brief description of each community type is presented below. For a more in-depth study of the tidal marshes of the York River see Wass and Wright (1969), Silberhorn (1999), EPA (1983), and Perry and Atkinson (1997).

MARSH TYPES

Saltmarsh Cordgrass (a.k.a. Smooth Cordgrass) Community

The saltmarsh cordgrass community dominates the poly- and mesohaline areas of the York River (Figure 1). The community is comprised of dense, often mono-specific stands of *Spartina alterniflora* (saltmarsh or smooth cordgrass). Physiographical distribution ranges from mean sea level (MSL) to approximately mean high water (MHW). A stout, erect species, *S. alterniflora* often is represented by two forms: a tall form, 1.2-2 m (4-6ft) in height along the waters edge or along levees; and a short form 0.7 m (2ft) or less in height found in poorly drained areas behind levees or at elevations slightly higher than mean high water (Silberhorn, 1999). Other vegetative communities occur landward of the saltmarsh cordgrass communities including the saltmeadow, black needlrush, saltbush, and panne communities.

Figure 1. Saltmarsh cordgrass (*Spartina alterniflora*) (Photo courtesy of VIMS CCRM)

Natural succession of the saltmarsh cordgrass community for temperate climates analogous to the York River was first described in the 19th century (Mudge, 1862, Shaler, 1885) and is an important aspect of the marsh in respect to our current rise in sea level. These early researchers noted trees were positioned in an upright position at the bottom of saltmarsh peat. Mudge (1862) concluded that the stumps indicated that the area was once located at an elevation above MHW. He further noted *Spartina patens* rootstock, a species normally found at an elevation above mean high water, well below that elevation. He hypothesized, therefore, that saltmarshes "grew" (i.e., accreted) through the gradual accumulation of cordgrass rootstock. Several studies have shown that peat accumulation over time is responsible for the horizontal soil profile found in mid-Atlantic saltmarshes (Blum and Christensen, 2004). Primary succession normally occurs on a protected sand beach or overwash area. As the plant community matures, a solid subterranean root-mat develops. With sea level rises, the root-mat becomes anaerobic and creates reduced chemical conditions in the soil. Low redox conditions make it difficult, if not impossible, for aerobic soil microbes to survive. Without the presence of soil oxygen, biological degradation of the dead root material is considerably slower. The net effect is an increased amount of organic material in the soil and an increase in elevation in response to relative sea level rise (Redfield and Ruben, 1962, Redfield, 1972). Oertel *et al.*, (1989) have shown that a similar process has occurred and is responsible for the saltmarshes of the barrier islands of Virginia. Similar processes of marsh overwash and development are ongoing on a smaller scale within the Chesapeake Bay and its tributaries.

Saltmeadow Community

The saltmeadow community dominates areas of slightly increased elevation located landward of the saltmarsh cordgrass community in meso- to polyhaline waters. It also occurs on the higher portion of natural levees. The dominant vegetation is either *Spartina patens* (saltmeadow hay; Figure 2) or *Distichlis spicata* (salt grass) or a mix of both. Topographically, these "meadows" often remind one of grassland prairies or hay fields. Historically, these marshes have been used as a source of cattle fodder, both grazing and haying, throughout the mid-Atlantic and New England states (Teal and Teal, 1969). Both dominant plants form characteristically dense, low, 0.3-0.7 m (1-2 ft), wiry meadows typically with swirls or cow-licks.

Black Needlerush Community

The black needlerush community (Figure 3) is found interspersed among the saltmeadow community, and is common in the high marsh of some meso- and oligohaline areas. *Juncus roemerianus* (black needlerush) nearly always grows in mono-specific stands. The dark green (almost black), leafless stem tapers to a sharp point, giving the plant it's well deserved

Figure 2. Saltmeadow hay (*Spartina patens*) (Photo courtesy of VIMS CCRM)

name. The black needlerush community is normally located behind and/or interspersed within the Salt Marsh community. The boundary is usually distinct (Eleuterius, 1976, Montague *et al*., 1990). Stout (1984) divided black needlerush into three communities based upon elevation and soil salinity influences (modified from Uchytil, 1992): (1) Saline needlerush marsh. Found in eury- to mesohaline waters. Common associates include smooth cordgrass, saltmeadow cordgrass (*S. patens*), giant cordgrass (*S. cynosuroides*), saltgrass *Distichlis spicata*), and glasswort (*Salicornia* spp.). (2) Brackish needlerush marsh. Transitional between Meso- to oligohaline marshes. Associates include smooth cordgrass, giant cordgrass, saltmeadow cordgrass, sea lavender (*Limonium caroliniana*), threesquare, and common arrowhead (*Sagittaria latifolia*). (3) Intermediate needlerush marsh, transitional between brackish and tidal freshwater marsh. Associates include common reed (*Phragmites australis* v. australis, P. a. v. *americanus*) and softstem bulrush (*Scheonoplectus tabernaemontani*).

Figure 3. Black needlerush (*Juncus romerianus*) (Photo courtesy of VIMS CCRM)

Saltbush Community

Landward of the salt meadow and needlerush marshes one encounters the only tidal saltmarsh community dominated by woody vascular plants. The saltbush community is dominated by two shrubs: *Iva frutescens* (salt bush; Figure 4) in the lowest physiographic range, and *Baccharis halimifolia* (groundsel tree; Figure 5) in the higher physiographic range of the marsh. This type of vegetation usually delineates the upward boundary of the tidal marsh. The shrubs usually reach heights of 1 to 4 m (3-12.5ft.).

Figure 4. Saltbush (*Iva frutescens*) (Photo courtesy of VIMS CCRM)

Figure 5. Groundsel Tree (*Baccharis halimifolia*) (Photo courtesy of VIMS CCRM)

Big Cordgrass Community

The big cordgrass community, dominated by *Spartina cynosuroides*, (big cordgrass; Figure 6) is found slightly above MHW, but is variable in range (Silberhorn, 1999). It usually forms dense, mono-specific stands in low salinity (oligohaline) marshes. This is one of the tallest grass species of our tidal wetlands, usually reaching 2-4 m (6-12 ft) in height. Its stems are stout, leafy, and have a distinct coarse branched flower (seed) head. The leaves have saw-like margins that easily lacerate human skin.

Figure 6. Big Cordgrass (*Spartina cynosuroides*) (photo courtesy VIMS CCRM)

Cattail Community

Although there are several species of cattails in the mid-Atlantic region, there is only one, *Typha angustifolia* (narrow-leaved cattail; Figure 7) that is common in the saline tidal reaches. The community is usually found in isolated stands in brackish marshes, often near the upland margin where there is freshwater seepage. In freshwater areas, *T. latifolia* (broad-leaved cattail) may also be present and is often an indicator of high nutrient loads.

Figure 7. Narrow-leaved Cattail (*Typha angustifolia*)

Reed Grass Community

The reed grass community has become quite controversial. The community is dominated by reed grass (*Phragmites australis* ssp. *australis*, *P. a.* ssp. *americanus*; Figure 8), a species considered invasive by many wetlands scientists, regulators, and managers. The community is usually located above MHW and is almost always associated with topographic or other disturbance such as the placement of dredged sediments or other fill material, plant die-back or surface erosion. The species usually cannot tolerate poly- or mesohaline conditions below MHW (Silberhorn, 1999). It is a tall, stiff grass up to 4 m (12 ft) in height with short, wide leaves tapering abruptly to a pointed, purplish plume-like (feathery) flower head that turns brown in seed.

Figure 8. Reed Grass (*Phragmites australis* ssp. *australis*) (Photo courtesy of VIMS CCRM)

Salt Panne Community

Salt pannes (Figure 9) are shallow depressions, which often form within the interiors of large saltmarsh cordgrass communities. They are usually the result of wrack accumulation that kills the cordgrass or of "eatouts" caused by muskrats or snow geese. These areas normally become hyper-saline and are sparsely vegetated. They are dominated by several halophytic species of saltworts (*Salicornia virginica*, *S. europea* and *S. bigelovii*). These are succulent plants 1.5-30 cm (6-12 in) tall. By late summer, these plants may turn a dark red, giving those portions of the marsh a striking contrast to the yellow-greens of the surrounding grasses.

Figure 9. Salt panne with *Salicornia virginica*

Brackish Marsh Community

In the brackish marsh community (Figures 10 and 11) no single species typically covers more than 50% of the marsh and species diversity is much higher than the saltmarsh cordgrass community that occurs in areas of higher salinities (usually 15 to 20 ppt or higher). Typically, associated vegetation includes: saltmarsh cordgrass, saltmeadow hay, saltgrass, black needlerush, saltbushes, threesquare bulrush, big corgrasss and cattails. Small areas within the marsh may be dominated by one or more species as many are distrubted throughout the marsh according to their tolerance for both inundation and salinity. The wetland vegetation is distributed vertically from mean sea level, where saltmarsh corgrass dominates, to the upper limits of tidal inundation, where the saltbushes occur (Figure 10).

This marsh type is considered a microcosm of all the communities found in saline water and is ranked along with the Saltmarsh Cordgrass community as one of the highest valued

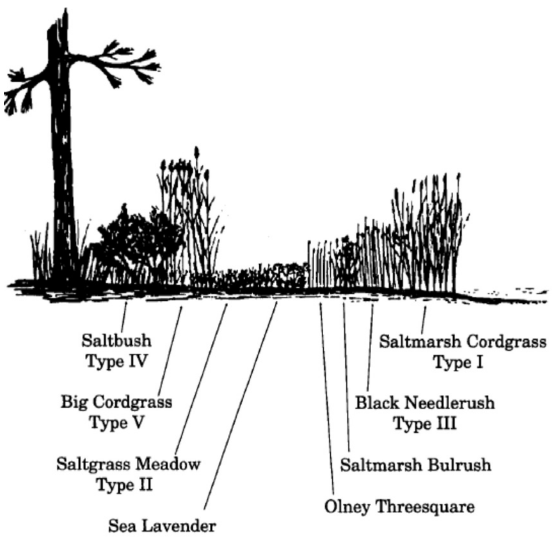

Figure 10. Brackish Water Mixed Community showing distribution of plant species from creek edge to upland. (Reproduced from VMRC 1993)

Figure 11. Brackish Water Mixed Community showing distribution of plant species from creek edge to upland. (Photo courtesy of VIMS CCRM)

marsh areas in Virginia because of its productivity, diversity and value as erosion, water quality control and flood buffering. Because of their location in low to moderate salinity areas many are know spawning and nursery grounds for finfish and crabs. They also are important as a valuable foraging area and habitat for a wide diversity of wildlife species.

Freshwater Mixed Marsh Community

In the freshwater Mixed Marsh Community (Figures 12 and 13) no single species covers more

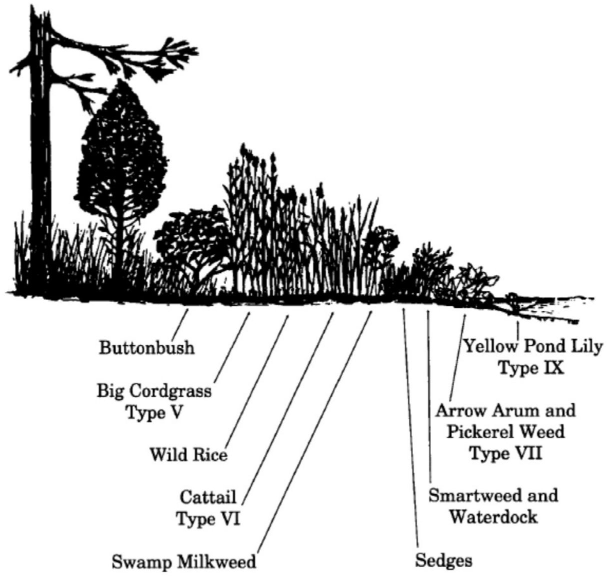

Figure 12. Freshwater Mixed Community showing distribution of plant species from creek edge to upland. (Reproduced from VMRC 1993)

than 50% of the site and in the York River more that 50 species may be found within a single marsh. There may be both considerable temporal and spatial variability in the abundance of individual species in this marsh community type with principle factors affecting the dominance including: season,

Figure 13. Freshwater Mixed Community (Photo courtesy of VIMS CCRM)

elevation and salinity or conductivity of the tidal waters. Figure 10 shows a characteristic distribution of dominant species extending from the creek or river edge to the upland for freshwater marshes in this region. Here the emergent marsh extends from below low water to the upper limits of storm tidal inundation. Yellow pond lily (*Nuphar luteum*) may be found growing below low water, however its leaves and flowering shoots must extend above the usual high tide. Arrow arum (*Peltandra virginica*) and pickerel weed (*Pontederia cordata*) are dominant at low to mid tidal elevations and in the spring and early summer may dominate large areas of the marsh. During the mid to late summer an over story of wild rice (*Zizania aquatica*) and other species may develop as the early species die back. Highest elevation will support big cordgrass, cattails and various small trees and shrubs such as buttonbush.

The freshwater mixed community has one of the highest annual productions of tidal wetlands in this region with annual production exceeding 1800 kg ha-1. These marshes are also highly valuable for wildlife and waterfowl as the plants produce a diversity of abundant seeds, roots and tubers that are readily consumed. Typically, tidal waters are important spawning and nursery grounds for many resident and anadromous fish such as the striped bass, shad and river herring. The marshes are also important as flood and erosion buffers and sediment filters, however much of the aboveground vegetation dies back in the winter creating broad mudflats. Sediments are readily trapped during the growing season however enabling most of these areas to maintain themselves under conditions of rising sea level. Salinity intrusions during years of drought may significantly change the community structure within one year's time (Davies, 2004) as more salt resistant species dominate. A broad diversity of species helps to maintain this flexibility.

CBNERRVA TIDAL WETLANDS

Goodwin Island

The wetland types within the Goodwin Island complex (see Hobbs, this Issue, Figure 3) include smooth cordgrass, black needlerush, salt-meadow hay, and tall reed marshes. The smooth cordgrass marshes make up a predominant portion of the Goodwin Island marshes. They are dominated by smooth cordgrass (*Spartina alterniflora*) with few other species present. Several small salt pannes, less than 200 m^2 and dominated by scattered patches of saltgrass (*Distichlis spicata*) and glasswort (*Salicornia virginica* and *S. bigelovii*), exist scattered within the northern smooth cordgrass marsh communities. A 1-2 m wide berm, approximately 0.5 m height, is found on the north, south, and west border of the islands. The berms are dominated by salt bushes (*Iva frutescens*) and salt meadow hay (*S. patens*) (Laird, 2001). No berm is found on the east side, having been eroded by wave activity (Perry, personal observation). Here, smooth cordgrass dominates to the edge of the marsh.

A large salt-meadow hay community exists on the west side of the islands, inland of the smooth cordgrass community. The community is dominated by a mix of salt meadow hay and saltgrass. Other species present include: marsh aster (*Aster tenuifolius*), *Fimbrisstylis autumnalis* (no common name), smooth cordgrass, and water parsnip (*Sium suave*) (Laird, 2001). Fires are a common disturbance in this community, as well as the tall reed community (see below) and maritime forest found on the largest island.

A large (approx. 13 ha) tall reed type community is located on the south-east side of the largest island, landward of the smooth cordgrass marsh. Dominated by tall reed (*Phragmites australis* ssp. *australis*), few other species were present (Laird, 2001). Small patches of tall reed also exist on the east side of the largest island; however, they are constantly eroding away (Perry, personal observations). Reserve managers are actively working to eradicate this invasive form of the tall reed (Reay, personal communications).

Several saline needlerush communities are found scattered throughout the salt marsh community on the southeast side of the largest island. These were usually monotypic and consisted solely of the black needlerush (*Juncus roemerianus*).

Overall, the dominant plant of Goodwin Island marshes is the saltgrass, followed closely by smooth cordgrass. Marsh aster, sea ox-eye (*Borrichia frutescens*), sea lavender (*Limonium carolinianum*), glasswort (*Salicornia virginica*) and (*Suaeda linearis*), all obligate halophytes, are common (Perry and Atkinson, 1997, Laird, 2001). Perry and Atkinson (1997) and Laird (2001) identified a total of eleven vascular plant species in the Goodwin Island marshes. Vascular plant diversity is low due to the stress of salt and inundation.

Catlett Islands

Catlett Islands (see Hobbs, this Issue, Figure 5) are comprised of a series of Holocene sand ridges and valleys. The ridges are covered with maritime forest dominated by *Juniperous virginiana* (eastern red cedar) and *Pinus taeda* (loblolly pine). The valleys are dominated by salt marsh communities; however several large saltmeadow communities existed in the high marsh zone. Numerous small monotypic stands of saline black needlerush are dispersed in the upper end of the salt marsh community. *Iva frutescens* (salt bushes) forms a thin ecozone (approx. 2 m, Laird 2001) between the tidal marshes and maritime forest. Erosion is common on the south and southeast side of the islands and, therefore, the saltmeadow communities may dominate to the waters edge.

Spartina alterniflora (salt marsh cordgrass) is the most common species in the tidal marshes with co-dominants *Distichlis spicata* (saltgrass), *Spartina patens* (saltmeadow hay), and *Juncus roemerianus* (black needlerush) (Perry and Atkinson, 1997). The Catlett Island marsh communities are very similar in distribution and composition to those of Goodwin Islands. Perry and Atkinson (1997) found only six species along a series of five wetland vegetation transects. Missing were the halophytes found in the more saline tidal marshes (e.g. *Borrichia frutescens*) (Perry and Atkinson, 1997, Laird 2001).

Taskinas Creek

Taskinas Creek (see Hobbs, this Issue, Figure 6) is comprised of a large watershed with embayment marshes. It receives a large freshwater input from runoff in its headwaters creating a sub-estuary system. Because of its topography, it contains both high and low marshes. It has a 1 m tidal range and a salinity range of 15-20 ppt at the mouth (reference CBNERR-VA data) to <0.05 ppt at the headwater. The beaver (*Castor canadensis*) plays an important role in the headwater of this ecosystem. They have built long dams across the headwaters that are several decimeters high. New growth of swamp forest is found upstream of the dams (see Reay, this issue). Downstream of the dams are found a large array of wetland types from tidal freshwater to brackish to smooth cordgrass type communities. Berms and high organic content of soil characteristic of salt marsh communities are located near the mouth and decreases as one moves upstream and nears the tidal freshwater marshes (freshwater mixed community).

Spartina alterniflora dominate the marshes at the junction of the York River and Taskinas Creek. Originally, a large high marsh zone of *Iva frutescens* (saltbush) inhabited the north end of the marsh at the junction where it was presumed that the *S. alterniflora* had eroded away earlier (Perry and Atkinson, 1997). On a current data-gathering trip (Perry, unpublished data 2006), we noted that most of the *I. frutescens* has now eroded away and that that remains has died back, apparently from an increase in inundation. The remaining highmarsh, which appears to be rebuilding by sand washing onto the marsh during storms, has become dominated with *S. cynosuroides* (tall cordgrass). Freshwater species such as *Juncus geradii* (military rush) and *Schoenoplectus pungens* were first found in the high end of this marsh.

Moving upstream approximately 1 km, *S. cynosuroides* becomes more dominant on the edges and the points (tips) of the marshes while the saltmeadow communities became more common in the interior, indicating a possible increase in marsh elevation (Laird, 2001). The saltmeadow community was dominated by *S. patens* and *D. spicata* (Perry and Atkinson, 1997, Laird, 2001). *Schoenoplectus robustus* (saltmarsh rush) dominated some small areas (less than 100 m^{-2}), scattered throughout the mid-marsh and marsh edges. *Schoenoplectus pungens*, and *Typha angustifolia* are commonly scattered to along the landward margin of the marshes. Perry and Atkinson (1997) note that ten species occurred in the mesohaline marshes, however, they noted that there were fewer obligate halophytes.

Taskinas Creek has moderate diversity overall due to the diversity of habitats. Diversity is low in marshes located near mouth (characteristic salt marsh communities) and jumps in the freshwater mixed community located approximately 2 km upstream.

Sweet Hall Marsh

Sweet Hall marsh (see Hobbs, this Issue, Figure 8) is a 440 ha. point marsh with a moderate forested watershed located on its north boundary. The wetland is dominated by low tidal marshes with a 1 m tide range. Salinity varies from <0.05 ppt to >15 ppt and is responsive to freshwater flows (CBNERR-VA data). Moderate freshwater input from runoff enters through the north forested area and from upstream. Upstream channel causes diversion of freshwater ebb-flows to use a southwest rout around the marsh. Flood-flows, on the other hand, travel through the major cross-marsh channel (see Hobbs, this issue, Figure 8). Wrack lines form berms on the rive edge up to 5 m wide. The berms are dominated by either a mix or low diversity stand of *S. cynosuroides*, *P. australis* ssp. *americanus* (tall reed grass), *Peltandra virginica* (arrow arum) and *Carex hyalinolepis*. More salt tolerant species are found on the downstream edge (east edge) than the upstream edge (west). Muskrat activity is common and appears to play a role in hydrology and composition of vegetation community (Doumlele, 1981, Perry and Hershner, 1999).

Wetland types include large areas of freshwater mixed communities, with a thin band of *Peltandra virginica* (arrow arum) along the lower elevations of the waterward fringe. A small Spatterdock community (dominated by *Nuphar luteum* (spatter dock)) is found midway down the upstream (west) side of the marsh. Fifty-six species were encountered by Perry and Hershner (1999) along a series of seven transects dissecting the marsh. Salt tolerant species (facultative halophytes) were poorly represented, but fresh water species were common. *Peltandra virginica* (arrow arum) is the dominant species in the mixed marsh areas, particularly in the first half of the growing season (Doumlele, 1981,Perry and Atkinson, 1997, Perry and Hershner, 1999, Davies, 2004). Co-dominants include: *Carex stricta*, *Leersia oryzoides* (rice cut-grass), *Polygonum punctatum* (spotted knotweed), and *P. arifolium* (tear-thumb). Late in the growing season, grasses such as *Echinochloa walteri* (Walter's millet), *Leersia oryzoides*, and *Zizania aquatica* (northern wild rice), and composites such as *Bidens laevis*, *B. cernua* (marsh beggar ticks), and *Pluchea odorata* (marsh fleabane) will become prominent, each dominating large, but highly diverse regions of the marsh (Doumlele, 1981, Perry and Hershner, 1999, Davies, 2004). Plant diversity is higher than that of the salt marshes and brackish marshes of the York River (Doumlele, 1981, Perry and Atkinson, 1997). While few obligate or facultative halophytes are present, their numbers have been increasing over past several decades (Perry and Hershner, 1999, Davies, 2004).

TIDAL MARSH FAUNA

The dominant fish species from Goodwin Island, based on biomass and total number of fish caught, was *Fundulus heteroclitus* (mummichogs) (Ayers, 1995, Cicchetti, 1998). Ayers (1995) reported that biomass peaked in Goodwin Islands in June, with a second peak in late September. Cicchetti (1998) found that *F. heteroclitus* used seagrass beds, unvegetated areas, and portions of the marsh as a low tide refuge. In all, there were 32 species of nekton captured between June and October 1995, with a mean overall abundance of 28.6 individuals per m^2 and a mean biomass of 3.89 g/m^2 (dry weight). Based only on biomass, the most dominant species was the blue crab, *Callinectes sapidus* (Cicchetti, 1998). Certain fish from the sciaenid family (e.g. white croaker, spot croaker, and weakfish) use marsh habitats in a transient or opportunistic manner, as do silversides (*Menidia menidia*). As well, the marsh surface is apparently used as a nighttime refuge by silversides. Cicchetti and Diaz (2000) found that predation on invertebrates was highest in marsh edge areas and a large portion was consumed by transient species. The major path for export of material from the marsh interior habitats into shallow water habitats was by blue crab predation on resident mud fiddler *Uca* and *Sesarma* crabs (Cicchetti, 1998, Cicchetti and Diaz, 2000).

Few studies have addressed fauna of marshes and adjacent tidal streams in freshwater habitats (see Brown and Erdle, this Issue). Tidal freshwater marshes have been reported to be more diverse than salt marshes for certain fish taxa and for earlier life stages, as well as for other vertebrate groups (Odum *et al.*, 1984, Odum, 1988). Only non-insect invertebrates were reported to be less diverse in tidal freshwater marshes than in salt marshes (Odum, 1988). In a review of the literature, Brinson *et al.*, (1981) found insect abundance and diversity was high for salt and freshwater systems, which was taken as evidence that low diversity vegetation (i.e. salt marshes) can still support diverse consumer assemblages. Muskrat (*Ondatra zibethicus*) are a commonly occurring mammal in many tidal fresh and brackish marshes (sensu Brinson *et al.*, 1981, Odum, 1984). Connors *et al.*, (2000) detected significant nitrogen cycle effects due to muskrat activities in tidal freshwater marshes, but concluded that their effect on vegetation structure was limited. *Aeschynomene virginica*, a vascular plant with the federally status of threatened and Commonwealth of Virginia status of endangered, has been identified in several muskrat eatout areas in the tidal freshwater marshes of the Mattaponi, Pamunkey, and Rappahannock rivers. Black rat snakes (*Elaphe obsoleta*), brown water snakes (*Nerodia taxispilota*), and diamondback terrapins (*Malaclemys terrapin*) have all been observed in all four CBNERRVA tidal marshes. Virginia rail have been seen and heard in Sweet Hall and Goodwin Island marshes (several nest were encountered at both sites) (Perry, personal observations).

RESEARCH AND MONITORING NEEDS

Changes in vegetation communities have been documented in Goodwin Island (Cicchetti, 1998, Cicchetti and Diaz, 2000, Laird, 2001) and Catlett Islands (Perry and Atkinson, 1997, Laird, 2001). On Goodwin Island these changes include loss due to eroding marsh faces (Cicchetti, 1998, Cicchetti and Diaz, 2000, Laird, 2001) and the progression of an aggressive wetland invasive plant; *Phragmites australis*). Understanding the rate of erosion, and rate of spread of the *P. australis*, will help understand how these changes may alter the functions served by these marshes. The role of sea level rise and the ability of accretion in the salt marshes to keep up with the rise is poorly understood on all the York River marshes. More information on accretion rates, sediment composition, changes in above and below ground biomass, is needed.

The population decline of the diamondback (*Malaclemys terrapin*) terrapin, such as found in the marshes of the Goodwin Islands, Catlett Islands, Taskinas Creek and Sweet Hall Marsh reserve sites (Chambers, personal communications), is of national concern. Diamondback terrapin populations are threatened by juvenile and adult mortality in crabpots, loss of nesting habitat, and nest destruction by mammalian predators (Ruzicka, 2006). Raccoons (*Procyon lotor*) on Goodwin Island are known to play a major role in the decline (Ruzicka, 2006, Chambers, personal communications). It is not known, however, if the interaction is through natural trophic interactions (predator/prey relationship), or if there is an anthropogenic increase in raccoon populations (aka subsidization, sensu Klemens, 2000), that, therefore, may lead to an increase in predation on the terrapin. The brown water -snake (*Nerodia taxispilota*), has been seen on all four CBNEERVA sites (Perry, personal observations). Little is known of its habitat needs, population status, or the role it plays in the tidal marsh ecosystem.

As sea level rates increase, salinity and inundation period are also expected to increase. Data are needed to better understand the impact that these changes may bring to the tidal marshes in the York River. Several studies have documented changes in the vegetation communities of Sweet Hall Marsh (Perry and Hershner, 1999, Davies, 2004). These changes have been attributed to relative sea level rise since salt-tolerant perennial species, e.g. *Spartina alternifolia* and *S. cynosuroides*, have become more prominent (Perry and Hershner, 1999, Davies, 2004). Perry and Hershner (1999) predicted that salt – tolerant perennials will play a more important role in the future. Davis (2004) found that yearly changes in vegetation composition was more complex than believed and that both fresh and salt water perennial species had the ability to lay dormant through adverse environmental conditions. Research is needed to better understand the role of both annual and perennial plant species in vegetation succession brought on by sea level rise, and what any change in vegetation composition may mean to loss of, or changes in, habitat values of the marsh. Data on the potential changes in tidal marsh nutrient processes due to increased salinity in the water column and soil pore spaces (as a function of increased rates of sea level rise) is poorly understood. Both above and below ground carbon storage may be affected (Blum and Christian, 2004), altering nitrogen and carbon storage. However, these data are lacking.

Little is known about how an increase in nutrient input from agriculture, industry, and non-point sources may alter the turbidity of the water column and change the sediment content available to the York River marshes. The former effect may decrease the amount of photoactive light available to aquatic and marsh plants, as well as deliver toxic pollutants into the marsh. The latter may alter the available sediments needed by the marsh to keep up with increases in sea level rise rates.

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Submerged Aquatic Vegetation of the York River

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ABSTRACT

Submerged aquatic vegetation or SAV are important components of shallow water areas of the York River estuary. The plants that comprise these communities are distributed in shallow water areas (<2m) along the estuary from polyhaline to freshwater areas according to their individual salinity tolerances. Eelgrass *(Zostera marina)* is the only true seagrass and is found only in the lower York River where salinities average above 20 psu. It is a cool water species that decreases in abundance in the summer due to high water temperatures. SAV in this region have declined precipitously from historical abundances due to excessive levels of turbidity and nutrients. Infection of a marine slime mould-like protist, *Labyrinthula zosterae*, also impacted this species in the 1930s, nearly decimating it from this area. Widgeon grass *(Ruppia maritima)* co-occurs with eelgrass but can also grow in low salinity areas. Pondweeds *(Potamogeton)* and many other SAV species grow in both low salinity and freshwater areas. Macroalgae or "seaweeds" are currently a minor component of SAV in the York River system. Several algal genera common in the area include: *Agardhiella, Ulva, Enteromorpha* and *Chara*. While there has been a great deal learned through research and monitoring relative to SAV communities in the Chesapeake Bay, in general, and the York River, in particular, more efforts are needed to advance SAV protection and restoration to achieve the SAV restoration goals. Research efforts are needed to further understand the relationships between environmental conditions and SAV response and the interactions between of various stressors on SAV. Other areas for further research focus include investigations of the relationships between natural and restored SAV growth, survival and bed persistence and biological stresses including herbivory or secondary physical disturbance through foraging, bioturbation or other activities. One important need is to quantify the short and long term relationships between SAV decline and recovery and climatic factors such as storms, droughts, and temperature extremes that may be influenced by climate change.

INTRODUCTION

Submerged aquatic vegetation or "SAV" are non-flowering or flowering macrophytes that grow completely underwater. In the Chesapeake Bay region, the term "SAV" is usually used to refer to various rooted aquatic angiosperms or "underwater grasses" found growing in shallow littoral areas ranging from high salinity regions (Figure 1) to freshwater tidal environments. Approximately 20 species are commonly found throughout the Chesapeake Bay. Individual species are distributed based on their tolerances to environmental conditions including: salinity, light, temperature, nutrient levels, sediment type, and physical setting. Moore *et al.* (2000) found that the SAV communities in the bay can be grouped into four associations based largely on their salinity tolerances (Table 1).

Figure 1. Lower York River seagrass bed.

Beds of SAV are important habitats in the Chesapeake Bay region as both marine and freshwater SAV communities have been found to provide habitat, protection, nursery areas, and other functions for economically valuable fishery species (Lubbers *et al.*, 1990; Duffy and Baltz, 1998; Richardson *et al.*, 1998); are primary sources of food for waterfowl (Korschgen and Green, 1988; Perry and Uhler, 1988; Perry and Deller, 1996); serve as indicators of local water quality conditions (Fonseca *et al.*, 1982; Korschgen and Green, 1988; Dennison *et al.*, 1993, Moore *et al.*, 1996); affect key biogeochemical and sedimentological processes (Kemp *et al.*, 1984; Caffrey and Kemp, 1990, Ward *et al.* 1984, Moore, 2004); and decrease the potential for shoreline erosion by dampening nearshore waves and water flow (Fonseca, *et al.*, 1982; Fonseca and Cahalan, 1992, Koch and Gust, 1999).

SAV have declined precipitously from historical abundances (Orth and Moore, 1983; Brush and Hilgartner, 2000). In the York River this decline was greatest in the 1970s with some recovery since then (Figure 2). In the region of the Catlett Island reserve site the SAV have disappeared completely. In the lower estuary, while some SAV remain, they have been found growing down to much shallower depths than their former occurrence and the abundance and bed configuration of the SAV can vary significantly from year to year (Orth *et al.*, 2005).

Table 1. Chesapeake Bay SAV Species Associations. * indicates dominant species. (From Moore *et al.*, 2000)

ZOSTERA Community	*Zostera marina**
	Ruppia maritima
RUPPIA Community	*Ruppia maritima**
	Potamogeton perfoliatus
	Potamogeton pectinatus
	Zannichellia palustris
POTAMOGETON Community	*Potamogeton perfoliatus**
	*Potamogeton pectinatus**
	Potamogeton crispus
	Elodea canadensis
FRESHWATER MIXED Community	*Vallisneria americana**
	*Hydrilla verticillata**
	*Myriophyllum spicatum**
	Ceratophyllum demersum
	Heteranthera dubia
	Elodea canadensis
	Najas guadalupensis
	Najas gracilllima
	Najas minor
	Najas sp.
	Potamogeton crispus
	Potamogeton pusillus

Over the past 5 years there has been a continual decline of SAV beds from the region that includes the areas surrounding the Goodwin Islands reserve site (Figure 3). In addition,

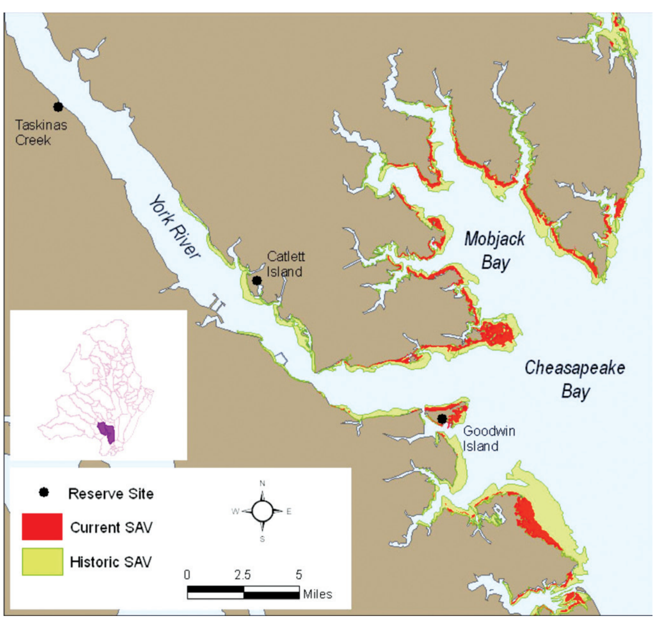

Figure 2. Current (2006) and historical (1950s) SAV distribution in the lower York River.

many areas that were formerly dominated by eelgrass are now vegetated with widgeon grass (Orth *pers. comm.*). This species tends to form beds that are less persistent and more variable that the eelgrass beds they replace. In contrast to the recent losses in the lower estuary, there has been a significant growth of SAV (Figure 3) in the upper tidal freshwater regions of the Pamunkey and Mattaponi Rivers due largely to recruitment of the non-native SAV, *Hydrilla verticillata*.

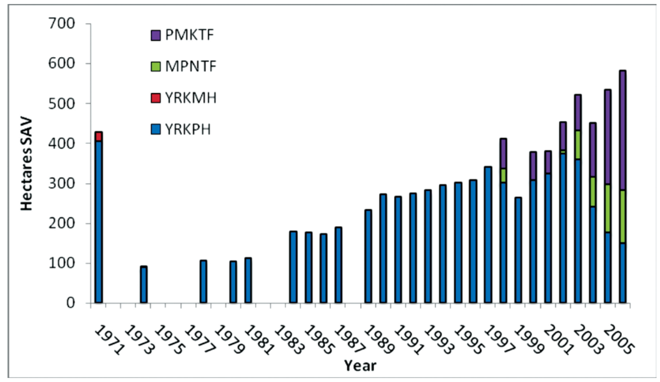

Figure 3. SAV abundance in the York River system. YRKPH-York Polyhaline. YRKMH-York Mesohaline. MPNTF-Mattaponi Tidal Fresh. PMKTF-Pamunkey Tidal Fresh.

There are a number of factors that can affect the local distributional changes in SAV abundance. The most important factor is water quality, especially as it affects the light available to the SAV leaf surface for photosynthesis (Moore *et al.*, 1997; Batiuk *et al.*, 2000, Kemp *et al.*, 2004). Light attenuation can occur both through the water column as well as through the epiphyte layer that forms on the photosynthetic surfaces. The latter can be 30% or more of total light attenuation for SAV in the Chesapeake Bay (Kemp *et al.*, 2004). Suspended particles, both living and nonliving, and dissolved materials in the water column attenuate light in general proportion to their concentrations (Kirk, 1994). Light attenuating material attached to photosynthetic surfaces of the plants themselves includes living plants and animals, detrital material, and sediments (Neckles *et al.*, 1993). The rate of accumulation of this material on the plants is generally related to the concentration of suspended particles, the availability of light and nutrients in the water column (Moore and Wetzel, 2000; Kemp *et al.*, 2004), and the rate of grazing or loss of material through physical factors (Neckles *et al.*, 1993; Duffy *et al.*, 2003). Other factors such as episodic storm events (Pulich and White, 1991), physical disturbance (Quammen and Onuf, 1993), and herbicide toxicity (Kemp *et al.,* 1985) can have local effects. Fishing, aquaculture and recreational boating practices can also affect SAV beds both directly through the use of the gear and placement of aquaculture structures, as well as indirectly through factors such as habitat deterioration (ie organic matter deposition and algae growth) and propeller scars from vessels attempting to traverse shallow areas. Given water quality conditions of adequate light for growth and limited nutrient concentrations, SAV beds are regulated by the physical, geological and geochemical conditions at a site (Koch, 2001).

Recruitment and growth of SAV can also occur as habitat conditions improve. In some cases the re-growth may be a result of the explosive growth of non-native species, especially in tidal freshwater and low salinity areas. This growth may result in persistent vegetation in these regions and may be accompanied by a simultaneous re-growth of more native species (Rybicki and Landwehr, 2007).

EELGRASS COMMUNITY

There are only approximately 60 species of seagrasses found world-wide (den Hartog, 1970; Green and Short, 2003). Seagrasses are thought to have evolved from flowering land plants beginning approximately 100 million years BP (Waycott *et al*., 2004). While seagrasses are a diverse group of plants they are generally characterized by a tolerance to salt water, reduced cuticle, no stomata, epidermal chloroplasts, reduced structural material in leaves, and flowers that are pollinated completely underwater. Eelgrass *(Zostera marina)* is the only true seagrass occurring in the Chesapeake Bay (Moore *et al*., 2000; Figure 4). It is the species which typically dominates in the higher salinity regions (>20 psu) of the Chesapeake Bay including the lower York River (Table 1). In this region eelgrass flower formation is initiated in the late winter (Silberhorn *et al*., 1983), seeds are released in May and germination begins in the fall as water temperatures drop below 20 °C (Moore *et al.*, 1993). Germination of seeds is reduced by oxygenated conditions (Moore *et al.,* 1993), therefore they must usually be incorporated into the sediment for germination to proceed. Most seeds of eelgrass do not appear to be widely distributed after release and are rapidly incorporated into the sediment (Orth *et al*., 1994). However, reproductive shoots of eelgrass can float and any seeds that remain attached can be transported many km (Harwell and Orth, 2002). There appears to be little in the way of a long term seed bank in eelgrass beds in the bay and it is hypothesized that the seeds only remain viable for a year or less. Ongoing research is attempting to evaluate this aspect of seed ecology. Eelgrass commonly reproduces through vegetative clonal growth by continually producing new leaves, rhizome internode segments and lateral shoots from a basal meristematic region. Typically, an individual eelgrass shoot consists of 3-5 strap-like leaves enclosed in a basal leaf sheath. As eelgrass grows, the base of the shoot pushes through the sediment. The rhizome acts as a storage organ and the roots function both in anchoring the plant and as the primary site for nutrient uptake (Pregnall, 1984). Although eelgrass is a perennial plant, individual shoots generally survive for one to two years and some vegetative shoots will differentiate and become flowering shoots during their second growing season (Setchell, 1929).

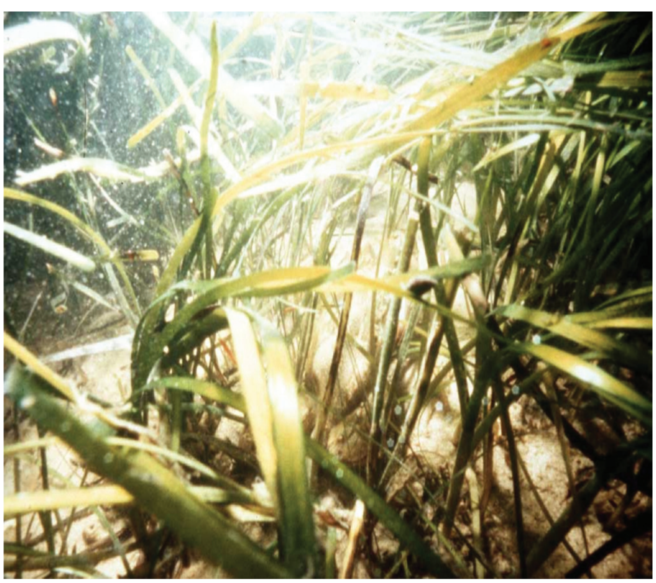

Figure 4. Eelgrass *(Zostera marina)*

Eelgrass is a polyhaline species and it does not usually survive in regions where salinities are commonly below 10 psu. In the lower York, eelgrass usually dominates in the deeper regions of beds out to water depths of 1.5m and is most abundant in this region at depths from 0.25m to 0.75m below mean low water (Orth and Moore, 1988). It is most abundant near the mouth of the York River in the vicinity of Goodwin Island. Historically, beds grew nearly continuously along the shoreline from the mouth of the estuary to several mi. upriver from the Catlett Island reserve site (Figure 2). On average eelgrass above ground biomass in this region ranges to 250 gdm m^{-2} (Moore *et al.*, 2000).

Eelgrass is a temperate species that is widely distributed along the North American coast from Newfoundland in the north to the North Carolina coastal bays in the south (Green and Short, 2003). Eelgrass populations in the Chesapeake Bay are therefore growing near their southern temperature limits. Here, beds reach maximum abundances in the late spring, dieback in the summer as water temperatures rise above 23°C, demonstrate some re-growth in the fall, and maintain low abundances throughout the winter (Orth and Moore, 1986; Moore *et al.*, 1996; Batiuk *et al.*, 1992). Summertime conditions therefore appear to be particularly stressful for these populations, although the production of carbon reserves during other times of the year can influence the survival throughout the summer (Burke *et al.,* 1996).

In addition to stresses from habitat conditions eelgrass populations have been decimated by a "wasting disease" that affected many Atlantic populations, including those in the Chesapeake and Virginia coastal bays, in the 1930s (Muehlstein, 1989). Eelgrass wasting disease symptoms are caused by the infection of a marine slime mould-like protist, *Labyrinthula zosterae* Porter and Muehlstein (Short *et al.,* 1987; Muehlstein *et al.,* 1988, 1991; Muehlstein, 1992) which has been reported in several species of *Zostera* (Short *et al.*, 1987, 1993). It was thought that Labyrinthula was a secondary decomposer of senescent leaves (den Hartog, 1987; den Hartog *et al.*, 1996). Ralph and Short (2002) have demonstrated that *L. zosterae* rapidly invades the healthy green tissue around black disease spots, impairing photosynthesis, and is a primary pathogen causing the wasting disease infection. Salinity plays a role in regulating disease activity (Burdick *et al.,* 1993) with higher infection levels typically found under higher salinity conditions. However, the actual conditions that initiate broad-scale die-off from the disease are not well understood. Although there have been records of eelgrass die-off infections from virulent strains of Labyrinthula in recent years (Green and Short, 2003) there is little evidence that this "wasting disease" is prevalent in Chesapeake Bay populations at the present.

WIDGEON GRASS COMMUNITY

Widgeon grass (*Ruppia maritima*; Figure 5) is the second most abundant species found in the higher salinity regions of the bay and a dominant species in the middle regions of the

Figure 5. Widgeon Grass *(Ruppia maritima)*

bay. In comparison to eelgrass, widgeon grass has a much broader salinity tolerance (Stevenson and Confer, 1978) and can be found from freshwater to high salinity areas throughout the bay (Moore *et al.*, 2000). Widgeon grass can grow at depths as shallow as mean low water (Orth and Moore, 1988) and can also be found in shallow panes in bay marshes as well as shallow road side ditches. It is usually a much less robust plant than eelgrass with average peak seasonal biomass of 100 gdm m^{-2} in this region compared to 250 gdm m^{-2} for eelgrass. Individual shoots are characterized by straight threadlike leaves 3 to 10 cm long and 0.5 mm or less wide (Figure 5). It has an extensive root system of branched, creeping rhizomes that produce vertical shoots with leaves. Widgeon grass has a higher temperature photosynthetic capacity compared to eelgrass (Evans *et al.*, 1986) and in the York River it reaches maximum abundance in mid-summer. At this time it can develop into a tall highly branched form with flowering shoots that extend to the water surface. Pollen released from the stamens floats on the water until it contacts the extended pistils. The fertilized flowers produce individual oval-shaped fruits with pointed tips enclosed in hard seed coats. The seeds may remain viable in the sediment for long periods. Like eelgrass it is a valuable food resource for water fowl (Schulthorpe, 1967; Martin and Uhler, 1951), however it can be more easily uprooted by storms and in the winter has much lower biomass. It is a rapid spreader and in recent years it has spread into many areas in the mid-bay where eelgrass has died off (Orth *et al.*, 2006). In beds mixed with eelgrass it will initially spread more rapidly than eelgrass into scars caused by boat propellers and other damaged areas. However it can eventually be replaced with eelgrass if that eelgrass is the more dominant for that bed. In the York River widgeon grass is only found mixed with eelgrass in the lower, polyhaline region of the estuary. In the Chesapeake Bay widgeon grass is usually the most abundant throughout the oligohaline and mesohaline regions of system (Moore *et al.*, 2000).

PONDWEED COMMUNITY

The pondweed community is dominated by several species of the Potamogeton including: *Potamogeton pectinatus* (sago pondweed) and *Potamogton perfoliatus* (redhead grass). Both species have some tolerance for salinity and are most abundant in the Bay at salinities of less than 10 psu (Stevenson and Confer, 1978). Typically, this community reaches greatest abundance in mid-late summer and on average has been found to have a peak biomass of 100 gdm m^2, although individual beds may reach much higher levels.

Redhead grass (Figure 6) is characterized by extensive, branching shoots with alternate, ovate, leaves that curl slightly. It can exhibit extensive morphological variation. Stevenson and Confer (1978) indicate that the variation bupleuroides is the most common variant found in the Chesapeake Bay. It is found in both fresh and brackish waters of the bay but more typically is found where salinities are 5-10 psu (Bergstrom *et al.*, 2006). Reproduction is both asexual, through extensive shoot and root/rhizome growth and overwintering buds, and sexual. Flowers extend above the water surface and pollen is carried by air. Seeds are produced in clusters at shoot tips.

Figure 6. Redhead Grass *(Potamogeton perfoliatus)*

Sago pondweed can form elongated stems up to several meters in length with fanlike clusters of filiform leaf blades extending to the water's surface. It reproduces both through vegetative and sexual processes. Sago pondweed grows through vegetative spread of shoots and roots. It also produces over-wintering tubers as well as specialized turions or winter buds (Sculthorpe, 1967). Pollination, fertilization and fruit development occur at the water/air interface (Yeo, 1965). Seeds form in clusters at the tips of the stems. Sago pondweed can be a prolific spreader and rapid colonizer through both extensive seed and tuber production (Stevenson and Confer, 1978). Although abundant in oligohaline regions of the Chesapeake Bay, sago pondweed has only been occasionally observed in the York River where it grows in small beds at the heads of small tributaries of the York. While not recorded in Taskinas Creek, the low salinity region at the upper limits of tidal influence in that tributary would be a potential site for sago occurrence. Like most of the SAV species discussed here, sago pondweed can be an important component of the diet of waterfowl and habitat for fish and invertebrates (Stevenson and Confer, 1978).

FRESHWATER MIXED COMMUNITY

Moore *et al.* (2000) have identified 12 species that have been observed in 10% or more of the samples of freshwater mixed SAV beds throughout the bay during the period of 1986 to 1996 (Table 1). While most of these species reach greatest abundance in areas with very low or no salinity, nearly all have some amount of salinity tolerance up to and exceeding 5 psu (Stevenson and Confer, 1978; Bergstrom *et al.*, 2006). Because of the tidal and climatic variations in the Bay, many areas with the freshwater mixed SAV community experience some level of salinity over time. The individual salinity tolerances of each species may, therefore, affect their composition in a bed over periods varying seasonally to annually. The three species described below have been found to dominate freshwater SAV beds throughout the bay, although individual small systems or beds may be dominated by a number of the other species found in this community type.

Wild celery *(Vallisneria americana)* is a valuable and important species that, unlike many of the canopy forming species characteristic of freshwater SAV in the Bay, grows long, strap-like leaves up to 2m in length, from basal clusters (Figure 7). Vegetative propagation of leaf clusters occurs through growth of stolons, while in the spring regrowth is from over-wintering buds. Sexual reproduction occurs as pistillate flowers are fertilized at the water surface with pollen from free-floating staminate flowers that break away from the plant base at anthesis (Sculthorpe, 1967). Wild celery is most abundant in the upper Chesapeake Bay, including the Susquehanna Flats, and its major tributaries such as the Potomac River (Orth *et al.*, 2006). In the York, beds have been observed in the Mattaponi River, but it may occur elsewhere in small beds, especially in freshwater regions of many small tributaries of the York.

Figure 7. Freshwater mixed SAV bed with wild celery and water milfoil.

Hydrilla verticillata (Figure 8) was first introduced into the US in the 1960s and since then has been found growing across the southeastern states to California (Bergstrom *et al.*, 2006). It was first found in the Potomac River in 1982 and since then has been observed throughout the upper Chesapeake Bay. Currently, in the York River system, it is abundant in oligohaline and freshwater areas in the Pamunkey and Mattaponi Rivers (Orth *et al.*, 2006). Hydrilla is a rapid colonizer, especially in shallow and protected water. It can reproduce through a variety of mechanisms including sexual reproduction where pollination occurs at the water surface. Asexual reproduction occurs from vegetative growth and fragmentation as well as the production of rootstock, tubers and turions (Bergstrom *et al.*, 2006).

Eurasian watermilfoil (*Myriophyllum spicatum*; Figure 7) has been a dominant species in the bay since the 1950s having been first introduced to the US from Europe in the late 1800s (Stennis *et al.*, 1962). It has undergone periods of explosive growth followed by declines, both in the Chesapeake Bay and elsewhere (Stevenson and Confer, 1978). Today it is a persistent component of many freshwater SAV beds, especially in the Potomac River and upper bay where it grows in protected waters (Moore *et al.*, 2000). It has not been observed in the York River system as yet. It can reproduce through flowering and seed formation, fragmentation, rhizome growth and bud formation (Patten, 1955, 1956). Biomass can be high, especially in regions of nutrient enrichment. Although an introduced species that has been subject to extensive weed control actions, especially in ponds and reservoirs, it is an important component of the diet of many species of waterfowl (Stevenson and Confer, 1978).

Figure 8. *Hydrilla verticillata*.

MACROALGAE

Macroalgae or "seaweeds" are currently a minor component of SAV in the York River system. Macroalgae are non-vascular plants lacking the more highly developed structures including flowers, roots, and transport systems found in aquatic angiosperms. Their initial evolution and development is thought to have preceded the aquatic angiosperms and seagrasses by hundreds of millions of years (Waycott *et al.*, 2004; Simpson, 2006). In many coastal systems undergoing anthropogenic eutrophication macroalgae may outcompete and displace seagrasses (Valiela *et al.*, 1997). There are several species that can be locally abundant, and given the declines of seagrasses in the higher salinity regions of the system, they may be providing some local habitat value for organisms such as the blue crab (R. Lipcius, VIMS, per. comm.).

There are few quantitative studies of seaweeds in the Chesapeake Bay (Ott, 1972; Orris, 1980). Humm (1979) provides the most comprehensive published review of macroalgae in Virginia waters. His summary indicates that many of the algae found in the bay include species of cold-water affinity that range from Cape Cod to North Carolina, and warm-water species that range from the Caribbean Seas northward to Cape Cod. Most species found here are of the cold-water affinity group, with many warm water species carried up into the bay from southern areas by ocean currents during the summer (Humm, 1979).

Several groups of seaweeds that are common in the bay include the red algae *Agardhiella* spp. (Agardh's Red Weed; Family Champiaceae) and Gracilaria spp. (False Agardhiella; Family: Solieriaceae). Both groups are very similar in appearance with a highly branched structure. *Agardhiella*; (Figure 9) is usually distinguished from *Gracilaria* by the lack of tapering branch bases. Both occur here as freely floating forms in large clumps and may accumulate in large abundances in sheltered, shallow water areas. They can be found in varying abundances within eelgrass and widgeon grass beds either

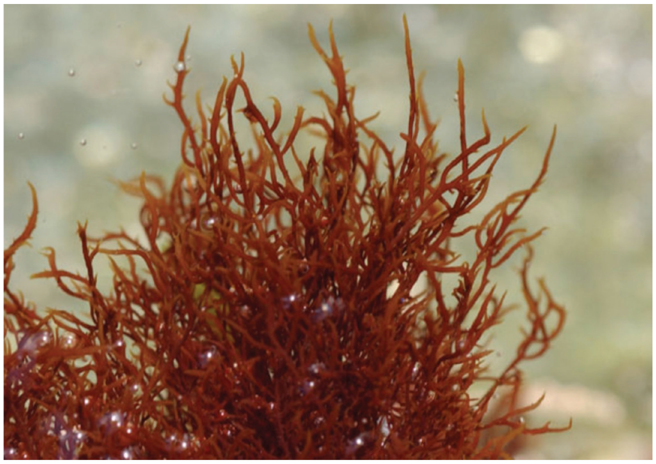

Figure 9. *Agardhiella* spp.

freely floating or attached to shell throughout the beds. There are also numerous other red algae found in the lower bay and lower York River during the summer (Humm, 1979) many are epiphytic on eelgrass and widgeon grass plants.

Several green algae which are abundant in the York River include *Ulva* spp. (Sea Lettuce; Family: Ulvaceae; Figure 10) and *Enteromorpha* spp. (Family: Ulvaceae; Figure 11). *Ulva* forms flat sheets resembling wilted lettuce that grows both free-floating and attached to shell, pilings and other structures. It can be found in salinities as low as 5 psu and can be especially abundant in areas of high nutrient enrichment. It has been found to accumulate in large abundances in eelgrass beds where it can both greatly reduce the light necessary for photosynthesis and smother the eelgrass (Brush and Nixon, 2003). *Enteromorpha* typically has thin, tubular fronds that are usually found throughout mesohaline and polyhaline areas attached to many structures including pilings, shells, invertebrate tubes, and even other SAV. Humm (1979) reports 11 species of *Enteromorpha* in Virginia waters with some forms resembling *Ulva*. Like *Ulva* it can reach dense abundances under conditions of high light and high nutrient availability, and has been observed to impact eelgrass in some areas of the world (den Hartog, 1994).

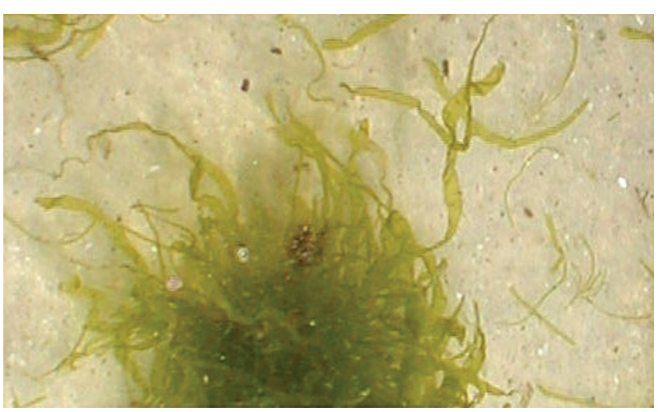

Figure 10. *Ulva* spp.

Figure 11. *Enteromorpha* spp.

In freshwater tidal regions of the York system, numerous filamentous green macroalgae occur. Under conditions of nutrient enrichment there is the potential for many to reach nuisance levels. Two common genera include *Spirogyra* and *Cladophora*.

Two common freshwater algae that resemble rooted SAV are *Chara* spp. (Muskgrass; Family Characeae; Figure 12) and *Nitella* spp. (Brittle Grass; Family Characeae). Both types are composed of whorls of leaf-like branches surrounding a central stem-like axis. They anchor to the sediment by root-like organs and can form large dense canopies extending to the water surface. Both can propagate through spores or fragmentation. They can be important food for ducks and their canopies can provide structure for fish similar to other SAV. Like many algae they can become prolific growers under high nutrient loads and can outcompete rooted SAV for shallow water habitat. Unlike other freshwater SAV they do not form significant overwintering structures and therefore are less valuable for migrating waterfowl in the winter in this region.

Figure 12. *Chara* spp.

RESTORATION OF SAV

Because of the importance of SAV to the bay ecosystem and the widespread and extensive declines that been observed since the 1970s, restoration of SAV has been an important component of Chesapeake Bay management for nearly 30 years (Batiuk *et al.,* 1992). And, due to the direct links between SAV and water quality there has been a focus on restoring water quality to levels (Table 2) below which SAV are present (Kemp *et al*., 2004) to enhance natural restoration.

To assist in this recovery, replanting efforts using both vegetative material and seeds have been undertaken. Eelgrass restoration has been studied using a variety of techniques in both Maryland and Virginia for a number of years (Orth *et al*., 2006). Currently efforts are focusing on the use of seeds, harvested from wild beds, to develop founder beds in areas where water quality may be suitable for SAV re-growth. Seeds are harvested in the late spring, held throughout the summer under ambient temperature and salinity conditions in shaded tanks, and dispersed in the fall just prior to natural seed germination. Restoration of freshwater SAV species has utilized a variety of techniques including tissue culture, shoot transplanting, and seed broadcasting (Moore and Jarvis, 2007; Ailstock and Shafer, 2006 a, b). In both Maryland and Virginia there are currently a number of programs where freshwater SAV are grown from seeds in classrooms (Figure 13) and then transplanted into the natural environment. Restoration results have demonstrated that SAV can be transplanted successfully in many areas; however, in some currently unvegetated areas herbivory of seedlings have limited restoration success (Moore and Jarvis, 2007).

Table 2. Chesapeake Bay water clarity habitat thresholds for SAV occurrence in different salinity zones. K_d-Light Attenuation, TSS-Total Suspended Solids, Chl-Plankton Chlorophyll a, DIN-Dissolved Inorganic Nitrogen, Dissolved Inorganic Phosphorus, PLW-Percent Light Through the Water to the SAV Plant, PLL-Percent Light to the SAV Leaf

Salinity Zone	K_d (m^{-1})	TSS (mg l^{-1})	Chl ($\mu g\ l^{-1}$)	DIN (mg l^{-1})	DIP (mg l^{-1})	PLW (%)	PLL (%)
Tidal Fresh (<0.5 psu)	<2	<15	<15	--	<0.02	>13	>9
Oligohaline (0.5-5 psu)	<2	<15	<15	--	<0.02	>13	>9
Mesohaline (5-18 psu)	<2	<15	<15	<0.15	<0.02	>22	>15
Polyhaline (>18 psu)	<2	<15	<15	<0.15	<0.02	>22	>15

Figure 13. Wild celery seedlings being grown by students in a classroom. (Photo courtesy Chesapeake Bay Foundation)

RESEARCH PRIORITIES AND MONITORING NEEDS

While there has been a great deal learned through research and monitoring relative to SAV communities in the Chesapeake Bay, in general, and the York River, in particular, more efforts are needed to advance SAV protection and restoration to achieve the SAV restoration goal. As diversity has long been recognized as important to a healthy ecosystem, more research is necessary to quantify the role of plant community diversity in restored and natural SAV bed persistence. Some unanswered questions include: What is the role, value and utility of colonizer species in natural and restored SAV bed succession? What is the role of non-native species in native SAV restoration, recovery, or decline? How are SAV community stability, succession and change related to environmental conditions? In addition, more information is needed to quantify relationships among patterns of abundance at the landscape-scale (bed size, etc.) and SAV growth, survival, and persistence. We are now just beginning to be able to investigate the relationships between environmental conditions and SAV response on high frequency temporal and spatial scales. One important need is to quantify the short and long term relationships between SAV decline and recovery and climatic factors such as storms (including physical stresses), droughts, temperature extremes, etc. We also must quantify the role of flowering success, seeds, seed banks and other propagules on SAV bed persistence, natural recovery and restoration if we are to fully understand the potential for natural recovery of areas that have improved habitat quality. Other areas for research focus include investigations of the relationships between natural and restored SAV growth, survival and bed persistence and biological stresses including herbivory or secondary physical disturbance through foraging, bioturbation or other activities. And finally given the complex nature of the estuarine system we must investigate the interactive effects of various stresses on SAV habitat requirements (eg. light availability and salinity).

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Phytoplankton of the York River

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ABSTRACT

The York River possesses a diverse phytoplankton community represented by a variety of algal species that includes both freshwater and estuarine flora. The mean annual monthly range of abundance is ca. 5-20 X 10^6 cells L^{-1} with an extended bi-modal pattern that begins with an early spring diatom peak (March) that declines into early summer. The development of a more diverse representation of taxa in the summer results in a secondary late summer-early fall peak. Diatoms are the dominant phytoplankton component throughout the entire estuary including a variety of pennate and centric species such as *Asterionella formosa* and *Aulacoseira granulata*. Dinoflagellates are more common and abundant in the lower segments of the York River where they have been associated with re-occurring and extensive "red tide" blooms. These include *Cochlodinium polykrikoides, Heterocapsa triquetra, Heterocapsa rotundata, Scrippsiella trochoidea*, and *Prorocentrum minimum*. Cynobacteria, commonly referred to as blue-green algae, include unicellular, colonial, and filamentous taxa that are predominantly freshwater species. Among the more common taxa are *Microcystis aeruginosa*, a potential bloom producer, *Merismopedia tenuissima, Oscillatoria* spp., *Dactylococcopsis* spp., *Chroococcus* spp. and *Synechococcus* spp. The cyanobacteria are generally considered a nuisance category that do not represent a favorable food resource, and are commonly associated with increased trophic status. Chlorophytes or green algae, including *Ankistrodesmus falcatus*, *Chlorella* spp., *Pediastrum duplex, Scenedesmus acuminatus* and *Scenedesmus dimorphus* are more common from spring to fall with lowest abundance in winter. Overall, the phytoplankton status in the York has been classified as poor/fair condition. Further studies are needed regarding interrelationships between the floral and faunal components of the plankton community and linkages to water quality and physical environmental factors in the system. In addition, continued observations regarding long-term trends in phytoplankton abundance and composition need to be followed with emphasis on any increasing presence of potentially harmful phytoplankton species.

INTRODUCTION

Phytoplankton are the microscopic plant communities present in water based habitats throughout the world. They are common components in ponds and lakes of various sizes, rivers, estuaries and the world oceans. Species within this category may vary from less than one micron to several mm in size, in addition to filamentous forms that are several cm in length. However, phytoplankton are most common as unicellular taxa, or as colonial species. Their significance is that they represent a major food source associated with numerous fauna in these aquatic habitats which they in turn are linked to other predators, including those leading to the higher trophic levels. Through the process of photosynthesis they are capable of harvesting solar energy in their transformation of basic substances in the water to multiply and represent a food and energy product for various animal species. In addition, a major bi-product of their photosynthesis is oxygen, which is released into the water as another essential commodity for biota in these habitats.

Phytoplankton development will be influenced by the availability of sunlight and specific nutrients in the water. However, an excess of these nutrients during favorable conditions for growth may result in a rapid increase in their abundance to produce an algal bloom. This condition is often so dense that due to the photosynthetic pigments in their cells, the blooms will be associated with a red or brown coloration in the water that is often referred to as a "red or mahogany tide." The environmental impact of these massive blooms may include a reduction or depletion of oxygen within these waters. Although these bloom producing algae normally include autotrophic oxygen producing species during daylight hours, with darkness and the cessation of photosynthesis, their continual respiratory demands often results in reduced oxygen levels in late evening hours, and may result in either fish kills, or general stress conditions among the fauna. The death of the massive numbers of bloom species and their accumulation in the sediment will subsequently involve their decomposition with associated oxygen uptake, also contributing to hypoxic or anoxic conditions in these waters. Fortunately, the bloom events are generally short-lived and due to their dissipation by river flow and tidal action, lower concentrations of these algae will eventually be re-established.

PHYTOPLANKTON COMPOSITION, ABUNDANCE, BIOMASS, PRODUCTIVITY

The York River possesses a diverse phytoplankton community represented by a variety of algal species that includes both freshwater and estuarine flora. The freshwater species come from the two major tributaries of the York River (Pamunkey River, Mattoponi River) and the streams and marshes bordering the York. A total of 231 taxa was reported for the Pamunkey River at a tidal freshwater site (Marshall and

Burchardt 2004a), with 254 species recorded within the York River (Appendix; Marshall, personal records). These species are well represented by a diverse assemblage of diatoms, chlorophytes, cyanobacteria, and cryptomonads, in addition to dinoflagellates, euglenophytes, and others (Appendix).

Many of the freshwater flora (ca. diatoms, chlorophytes, cyanobacteria) are abundant in the oligohaline regions, whereas, the lower reaches of the river remain dominated by estuarine diatoms and dinoflagellates (Marshall and Alden, 1990). This array of species will also change seasonally in the different regions of the river. There is a natural succession that begins with a spring flora dominated by several diatom species, followed by a mixed algal composition in summer and fall, with a reduced representation and abundance in winter. The representation of freshwater and estuarine flora in the York River will be influenced by river flow, tidal movement, and factors that impact extremes of these events, ca. spring rains, summer draught, periodic storms, etc. Haas *et al*. (1981) also addressed the influence of stratification and mixing to phytoplankton, with Sin *et al*. (2006) stressing the importance and control that abiotic conditions (e.g. resource limitation) have on the phytoplankton presence than biotic factors (predation). Marshall and Burchardt (2003; 2004a) in a study of the tidal freshwater Pamunkey stressed the importance of river flow to phytoplankton composition and productivity.

Since 1985, the composition and abundance of phytoplankton in the Pamunkey/York Rivers have been monitored in the Chesapeake Bay Monitoring Program. Productivity and autotrophic picoplankton analysis were subsequently added (e.g. Marshall and Alden, 1990; Marshall and Affronti, 1992; Marshall and Nesius, 1993; Marshall and Burchardt 2003, 2004a, b; 2005; Marshall *et al*. 2005b). Based on this data base the mean monthly phytoplankton abundance, total phytoplankton, biomass, chlorophyll a and productivity over this entire time period are given for station RET 4.3 in the York River (Figures 1-4).

The mean monthly phytoplankton concentrations (excluding the picoplankton) are given in Figure 1. These indicate an extended bi-modal pattern that begins with an early spring peak (March) that declines into summer. This is a period of transition from a major diatom development to a more diverse representation of taxa in summer that results in a late summer-early fall development. Lowest concentration will occur during mid-winter. The mean annual monthly range of abundance is ca. 5-20 X 10^6 cells L^{-1}.

Total phytoplankton biomass (which includes autotrophic picoplankton) is greatest during the spring diatom bloom, decreasing into early summer, followed by additional peaks in summer and autumn (Figure 2). The mean annual monthly range for algal biomass is ca. 2-10 X 10^8 pg C L^{-1}. Chlorophyll

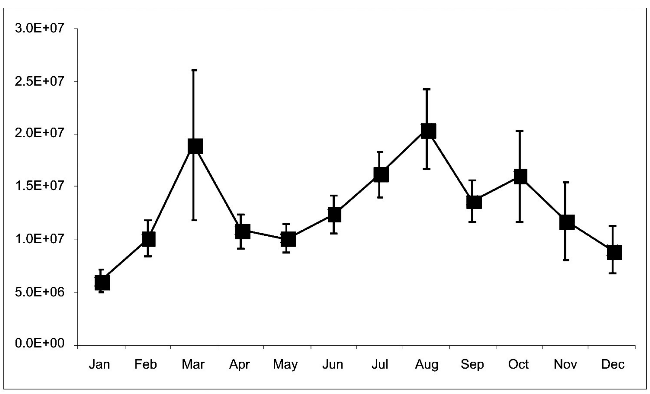

Figure 1. Mean monthly phytoplankton abundance (cells/L) 1985-2006, for station RET4.3 in the York River.

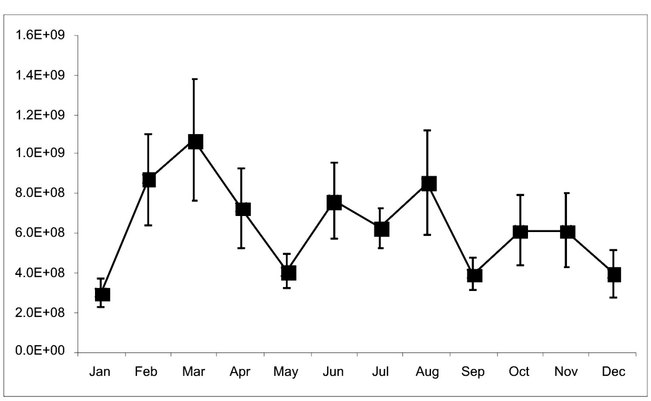

Figure 2. Mean monthly total phytoplankton biomass (pg C L-1) 1985-2006, for station RET4.3 in the York River.

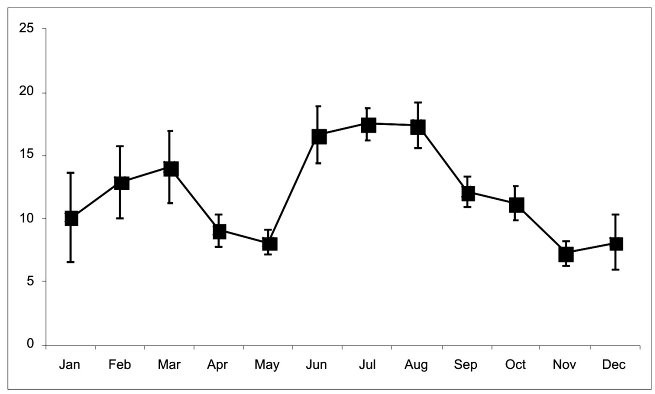

Figure 3. Mean monthly concentrations of Chlorophyll A (μg C L-1) 1985-2006 at station RET4.3 in the York River.

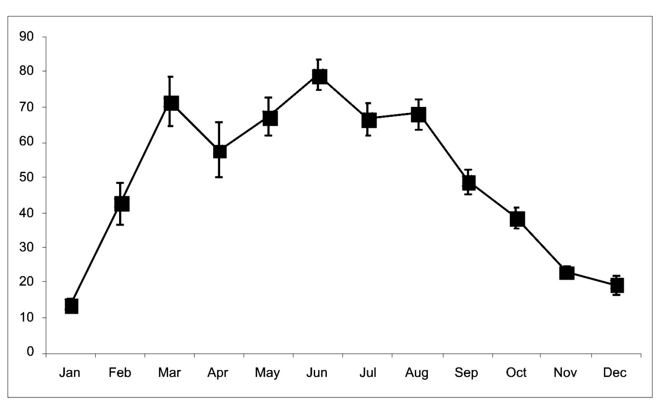

Figure 4. Mean monthly C14 productivity rates (mgC M3 h-1) 1989-2006, at station RET4.3 in the York River.

a concentrations will also vary over the year (Figure 3). However, they generally follow the phytoplankton concentrations with maximum amounts present during early spring and in summer, with mean monthly values ranging between 7-17 μg L^{-1}. Phytoplankton productivity is greater between March and August before decreasing to autumn and winter lows (Figure 7.4), with mean monthly rates from a January low to a June high of 13.7 and 79.1 9 mg C M^{-3} h^{-1} respectively.

DIATOMS

Diatoms are the dominant phytoplankton component throughout the York River in reference to their diversity, abundance, and biomass. They are represented by single cell, or short chain forming series of cells, that represent a major food source to the various faunal components in these waters. They are unique in having their cells enclosed within a cell wall of silica called a frustule, which is composed of two interlocking halves. The dominant freshwater diatoms in these waters include a variety of pennate *(Asterionella formosa)* and centric species (e.g. *Aulacoseira granulata*, *Aulacoseira distans*, *Cyclotella meneghiniana* (Figure 5), and *Skeletonema potamos*, among others) (Marshall and Alden, 1990; Marshall and Burchardt, 2005). In addition to these common plankton components in the water column, there are also a variety of taxa associated with the sediments and are composed of mainly pennate diatoms, which are also a major food source among the benthos. Many of these benthic species are regularly introduced into the water column during tidal mixing occasions. Diatoms will have a bi-modal spring/autumn pattern of development in the York River with a spring peak occurring in March with cell abundance ranging 8-18 X 10^6 cells L^{-1}. The winter low abundance is ca. 3 X 10^6 cells L^{-1}). Among the most dominant species are *S. potamos* upstream and *Skeletonema costatum* downstream. Diatom biomass values during the year will generally follow this same pattern as diatom abundance.

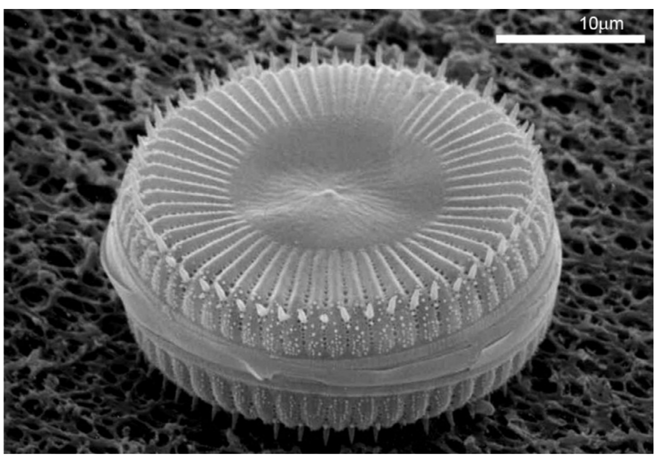

Figure 5. The diatom *Cyclotella meneghiniana*.

DINOFLAGELLATES

These are mainly unicellular species possessing flagella that allow movement in the water column. Many of these are autotrophic containing the necessary pigments to allow photosynthesis to occur, others lacking these pigments are heterotrophic and capable of engulfing small prey. There are others that are mixotrophic. The dinoflagellates are more common and abundant in the lower segments of the York River where they have been associated with re-occurring and extensive algal blooms. These include *Cochlodinium polykrikoides* (Figure 6), *Heterocapsa triquetra*, *Heterocapsa rotundata*, *Scrippsiella trochoidea*, and *Prorocentrum minimum* (Figure 7). Many of these taxa are associated with "red tide" events in these waters. The indigenous nature for many of these taxa is enhanced by their formation of cysts, or "resting" stages, which sink to the sediment following their motile stage in the water column and subsequently represent the "seed" population that produce the motile cells of the next generation of these flora to take place annually. Many of the dinoflagellates will have maximum growth periods and corresponding biomass occurring in early to late spring and again in autumn at concentrations that are 1-2 X 10^6 cells L^{-1}. Also there are the sporadic dinoflagellate blooms common in the lower York. Most conspicuous of these is caused by *Cochlodinium polykrikoides*, which has produced extensive blooms annually (Mackierman, 1968; Zubkoff *et al.*, 1979; Marshall, 1994). In 1992 its abundance reached 10^3 cells mL^{-1} in the York and regions of the lower Chesapeake Bay, with a massive bloom in the lower York occurring in 2005 that lasted over several days at 10^3 cells mL^{-1} (Marshall *et al.*, 2006a).

Figure 6. *Cochlodinium polykrikoides*, a common bloom producing dinoflagellate in the lower regions of the York River.

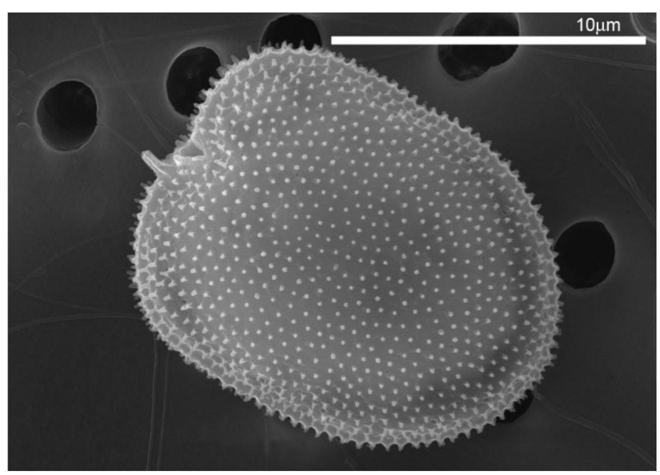

Figure 7. The common dinoflagellate *Prorocentrum minimum* in the York River.

CYANOBACTERIA

Species within this category represent a variety of forms, and are commonly referred to as blue-green algae. These include unicellular, colonial, and filamentous taxa that are predominantly freshwater species. In the York River these taxa are most common in the upper reaches of river, and in its two tributaries, with characteristically low abundance in the higher salinity regions of the river. Among the more common taxa in the York are *Microcystis aeruginosa* (Figure 8, a potential bloom producer), *Merismopedia tenuissima*, plus several *Oscillatoria* spp., plus *Dactylococcopsis* spp., and representative *Chroococcus* spp. and *Synechococcus* spp. The cyanobacteria are generally considered a nuisance category that do not represent a favorable food resource, and is commonly associated with increased trophic status. Their major development in the York occurs during summer and early autumn at ca. 3-8 X 10^6 cells L^{-1} before decreasing into winter months, with their total cell biomass representation following a similar pattern.

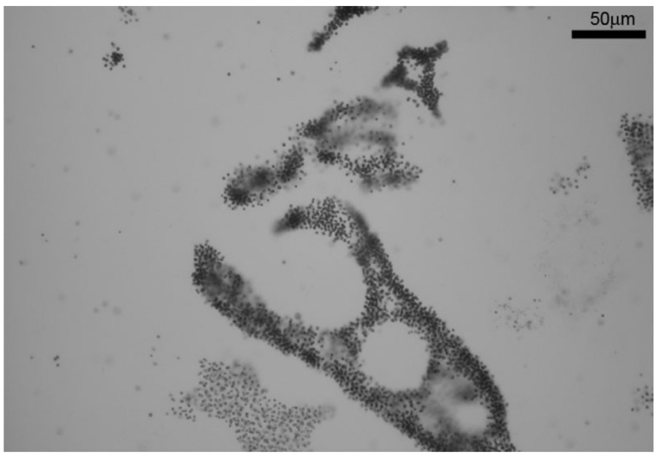

Figure 8. *Microcystis aeruginosa*, a colonial forming species of the cyanobacteria.

CHLOROPHYTES

These are common freshwater species, commonly known as green algae. Their high concentrations in the York River are more limited to the low salinity areas below the confluence of the Pamunkey and Mattoponi Rivers, but would increase in abundance downstream during high river flow. Their presence normally diminishes downstream. Common representation in the water column would be by *Ankistrodesmus falcatus*, *Chlorella* spp., *Pediastrum duplex*, *Scenedesmus acuminatus* and *Scenedesmus dimorphus*. Chlorophytes are more common from spring to fall with lowest abundance in winter. Their concentration levels are generally between 0.3-0.8 X 10^6 cells L^{-1} and usually these represent a small fraction of the algal biomass that would peak in summer.

AUTOTROPHIC PICOPLANKTON

This is a special phytoplankton category composed of cells less than 2 microns in size. The populations are composed of mainly single cell or colonial cyanobacteria, and to a much lesser representation by chlorophytes and other eukaryotes. Autotrophic picoplankton are ubiquitous throughout the year with their maximum development during the summer-early fall months with concentrations of ca. 2-4.5 X 10^8 cells L^{-1}. Their concentrations decline into autumn, with lowest levels during winter and spring. Their development during summer is a major contributor to the overall algal productivity, oxygen production, and food source for a variety of microorganisms.

OTHER CATEGORIES OF PHYTOPLANKTON

In addition to the more dominant flora mentioned above there are also a variety of background species that seasonally appear in lesser abundance and biomass, yet contribute to the overall photosynthetic activity and represent an additional food and oxygen source. The most common of these would be the cryptophytes, composed of a variety of motile single cell taxa present the entire year with mean monthly concentrations of ca. 1-3 X 10^6 cells L^{-1}, with peak concentrations during summer and autumn. These taxa include *Cryptomonas erosa* and *Rhodomonas minuta*. This group is a suitable food source for many of the heterotrophic dinoflagellates and zooplankton. Other algal categories are more frequently associated with the period following the spring diatom pulse and occur in summer and early autumn. For instance, the euglenophytes represent a category often showing pulses of significant size (3-4 X 10^4 cells L^{-1}), but are generally in low abundance. Upstream they include several *Euglena* spp., with *Eutreptia lanowii* more common downstream. *Trachelomonas*, and *Phacus* species are rare within the York. The same can be said of other eukaryotes that generally play a minor role in the phytoplankton dynamics in the river.

Among the different phytoplankton categories are also species that are considered harmful to other biota, or even be associated with human illness. Several are linked to toxin production, et al. related to anoxic or hypoxic conditions associated with bloom production (Marshall *et al.*, 2005). Examples of these potentially harmful species include the dinoflagellates *Akashiwo sanguinea*, *Cochlodinium polykrikoides*, *Dinophysis acuminata*, *Karlodinium micrum*, *Prorocentrum minimum*, *Pfiesteria piscicida*, *Pfiesteria shumwayae*; the diatom *Pseudo-nitzschia seriata*; the cyanobacteria *Microcystis aeruginosa*, among others (See Marshall *et al.*, 2005a for list of 34 taxa). Within the York River attention has recently been focused on increasing concentrations and any associated environmental impact related to blooms of the dinoflagellates *Cochlodinium polykrikoides*, *Karlodinium micrum*, and *Prorocentrum minimum*.

STATUS AND TRENDS

Using a 16-year database for stations in the Pamunkey/York River several significant long term phytoplankton trends have been identified in addition to several water quality variables (Marshall and Burchardt, 2004b). Increasing trends in total phytoplankton abundance and biomass were indicated along with similar increasing biomass trends for the diatoms, cyanobacteria, chlorophytes, and cryptomonads. There was a negative trend associated with the autotrophic picoplankton, with none indicated for the dinoflagellates. Of note, other trends included increasing TP concentrations, and decreasing TN:TP ratios (ca. 11.0). In this analysis there were also decreasing trends in Secchi readings matched with increasing levels of TSS.

A further appraisal of the York River phytoplankton habitats was included in the paper by Lacouture *et al*. (2006). They developed a phytoplankton index of biotic integrity based on a community structure protocol described by Buchanan et al. (2005), and using an 18-year data set coming from the Chesapeake Bay Phytoplankton Monitoring Program. This approach utilized a combination of nutrients (DIN, PO_4) and Secchi depth values to characterize the phytoplankton habitat conditions at sites in the Chesapeake Bay and several of its major tributaries within a variety of salinity ranges during spring and summer. A variety of phytoplankton metrics were chosen to provide a ranking for these locations (e.g. Poor, Fair, Good). In the characterization for the upper-river and lower river mouth sites in the York River, both received a spring status ranking of poor/fair, and in summer poor and poor/fair respectively. However, it should be noted that many of the sites in the Chesapeake Bay Monitoring Program included rankings of Poor and Poor/fair, with a Good ranking rare. A Poor (impaired) status was interpreted as having an excess of DIN or PO_4 levels and reduced water clarity that would be associated with the degree and composition of phytoplankton development at these locations. A Fair classification would represent an improved condition in one of these variables. Considering this classification, an increase in nutrient levels within the York would not be considered desirable for the environmental status in the York. Thus, although many of the phytoplankton trends are presently favorable, a continued increase in nutrient levels may easily end this pattern and produce a variety of less favorable species for food and oxygen production (including others that are potentially harmful) within the York River.

FUTURE RESEARCH NEEDS

Further studies are needed regarding interrelationships between the floral and faunal components of the plankton community and linkages to water quality and physical environmental factors within the various salinity regions and trophic levels in the system. In addition, continued observations regarding long-term trends in phytoplankton abundance and composition need to be followed with emphasis on any increasing presence of potentially harmful phytoplankton species. Each of these areas are linked to various important fin fish and shellfish resources utilized in the river and would be associated with their harvest and related socio-economic concerns.

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APPENDIX

York River Phytoplankton Species List

BACILLARIOPHYCEAE
Achnanthes sp.
Amphiprora alata
Amphiprora sp.
Amphora sp.
Asterionella formosa
Asterionella sp.
Asterionellopsis glacialis
Asterionellopsis karina
Aulacoseira distans
Aulacoseira granulata
Aulacoseira granulata var. *angustissima*
Aulacoseira islandica
Aulacoseira sp.
Bacillaria paxillifer
Bacteriastrum delicatulum
Biddulphia rhombus f. trigona
Cerataulina pelagica
Chaetoceros affinis
Chaetoceros compressus
Chaetoceros constrictum
Chaetoceros constrictus
Chaetoceros decipiens
Chaetoceros didymus var. *protuberans*
Chaetoceros neogracilis
Chaetoceros pendulus
Chaetoceros pseudocurvisetus
Chaetoceros socialis lauder
Chaetoceros sp.
Chaetoceros subtilis
Chaetocerus curvisetus
Cocconeis distans
Cocconeis sp.
Corethron sp.
Coscinodiscus centralis
Coscinodiscus concinnus
Coscinodiscus granii
Coscinodiscus oculus iridis
Coscinodiscus sp.
Cyclotella caspia
Cyclotella meneghiniana
Cyclotella spp.
Cyclotella striata
Cylindrotheca closterium
Cymbella sp.
Dactyliosolen fragilissimus
Delphineis surirella
Detonula pumila
Diatoma sp.
Diploneis sp.
Ditylum brightwellii
Eucampia zodiacus
Eunotia sp.
Fragilaria capucina
Fragilaria sp.
Gomphonema sp.
Grammatophora sp.
Guinardia delicatula
Guinardia flaccida
Gyrosigma balticum
Gyrosigma balticum silimis
Gyrosigma fasciola
Gyrosigma sp.
Hantzchia sp.
Hemiaulus hauckii
Hemiaulus membranaceus
Lauderia borealis
Leptocylindrus danicus
Leptocylindrus minimus
Licmophora sp.
Lithodesmium undulatum
Melosira jurgensii
Melosira moniliformis
Melosira nummuloides
Melosira sp.
Melosira varians
Meridion circulare
Navicula cuspidata var. *ambigua*
Navicula sp.
Nitzschia sp.
Odontella
Odontella mobiliensis
Odontella rhombus
Odontella sinensis
Paralia sulcata
Pinnularia sp.
Plagiogramma vanheurckii
Pleurosigma angulatum
Pleurosigma elongatum
Pleurosigma sp.
Proboscia alata
Proboscia alata gracillima
Pseudo-nitzschia pungens
Pseudo-nitzschia seriata
Psuedosolenia calcar-avis
Rhaphoneis amphiceros
Rhaphoneis sp.
Rhizosolenia imbricate
Rhizosolenia setigera
Rhizosolenia styliformis
Skeletonema costatum
Skeletonema potamos
Skeletonema sp.
Stauroneis sp.
Stephanopyxis palmeriana
Striatella sp.
Surirella ovalis
Surirella sp.
Synedra closterioides
Synedra sp.
Tabellaria sp.
Thalassionema nitzschioides
Thalassiosira anguste-lineata
Thalassiosira decipiens
Thalassiosira nordenskioeldii
Thalassiosira sp.
Thalassiothrix mediterranea
Tropidoneis lepidoptera

DINOPHYCEAE
Akashiwo sanguinea
Amphidinium acutissimum
Amphidinium crassum
Amphidinium extensum
Amphidinium sp.
Amphidinium sphenoides
Ceratium tripos
Cochlodinium brandtii
Cochlodinium polykrikoides
Cochlodinium sp.
Dinophysis acuminata
Dinophysis punctata
Dinophysis schroderi
Dinophysis sp.
Diplopsalis lenticula
Glenodinium sp.
Gonyaulax sp.
Gymnodinium danicans
Gymnodinium sp. <20 microns
Gymnodinium sp. >20 microns
Gymnodinium verruculosum
Gyrodinium fusiforme
Gyrodinium sp.
Heterocapsa rotundata
Heterocapsa triquetra
Karlodinium micrum
Katodinium asymmetricum
Noctiluca scintillans
Oblea rotunda
Oxyrrhis marina
Oxytoxum milneri
Rhizosolenia sp.
Peridinium sp.
Pfiesteria piscicida
Pfiesteria shumwayae
Polykrikos kofoidii
Prorocentrum aporum
Prorocentrum dentatum
Prorocentrum gracile
Prorocentrum micans
Prorocentrum minimum
Prorocentrum sp.
Protoperidinium breve
Protoperidinium brevipes
Protoperidinium conicum
Protoperidinium depressum
Protoperidinium divergens
Protoperidinium globulum

Protoperidinium granii
Protoperidinium minutum
Protoperidinium sp.
Scrippsiella trochoidea

PRYMNESIOPHYCEAE
Rhabdosphaera hispida

RAPHIDOPHYCEAE
Chattonella verruculosa

SILICOFLAGELLATES
Dictyocha fibula
Ebria tripartita

CYANOBACTERIA
Anabaena sp.
Aphanocapsa sp.
Aphanothece sp.
Calothrix sp.
Chroococcus limneticus
Chroococcus sp.
Coelosphaerium sp.
Dactylococcopsis raphidioides
Dactylococcopsis sp.
Gomphosphaeria aponina
Merismopedia elegans
Merismopedia punctata
Merismopedia sp.
Merismopedia tenuissima
Microcoleus sp.
Microcystis aeruginosa
Microcystis incerta
Microcystis sp.
Nostoc sp.
Oscillatoria sp.
Phormidium sp.
Spirulina sp.

EUGLENOPHYTA
Euglena acus
Euglena sp.
Eutreptia lanowii
Eutreptia sp.
Eutreptia viridis
Phacus spp.
Trachelomonas sp.

CHLOROPHYCEAE
Actinastrum hantzschii
Ankistrodesmus falcatus
Ankistrodesmus falcatus var. *mirabilis*
Ankistrodesmus sp.
Botryococcus sp.
Chlamydomonas sp.
Chlorella sp.
Closteriopsis longissima
Closterium sp.
Cosmarium sp.
Crucigenia crucifera
Crucigenia fenestrata
Crucigenia quadrata
Crucigenia sp.
Crucigenia tetrapedia
Desmidium sp.
Dictyosphaerium pulchellum
Dictyosphaerium sp.
Elakatothrix gelatinosa
Euastrum sp.
Kirchneriella sp.
Micractinium pusillum
Micractinium sp.
*Oocystis*sp.
Pandorina sp.
Pediastrum duplex
Quadrigula lacustris
Quadrigula sp.
Scenedesmus acuminatus
Scenedesmus abundans
Scenedesmus bijuga
Scenedesmus dimorphus
Scenedesmus quadricauda
Scenedesmus sp.
Schroederia setigera
Selenastrum minutum
Selenastrum sp.
Staurastrum americanum
Staurastrum sp.
Tetraedron regulare
Tetraedron sp.
Treubaria setigerum
Ulothrix sp.

CRYPTOPHYCEAE
Cryptomonas erosa
Cryptomonas sp.
Rhodomonas minuta

CHRYSOPHYCEAE
Apedinella radians
Calycomonas ovalis
Dinobryon cylindricum
Dinobryon sertularia
Dinobryon sp.
Synura sp.
Synura uvella

PRASINOPHYCEAE
Pyramimonas micron
Pyramimonas sp.

Zooplankton of the York River

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ABSTRACT

Zooplankton are a diverse group of heterotrophic organisms that consume phytoplankton, regenerate nutrients via their metabolism, and transfer energy to higher trophic levels. Over the past 40 years, few studies have specifically targeted zooplankton communities of the York River estuary and tributaries. However, several studies targeting specific taxa, and time series of multiple taxa, provide an emerging view of York River zooplankton community composition and how zooplankton communities change seasonally, and over longer time scales. Microzooplankton communities are dominated by ciliated protozoa, and rotifers are important in fresher water regions. In the lower Bay microzooplankton abundance peaks in spring, and in mid-summer to early fall. The mesozooplankton community is dominated by calanoid copepods *Acartia tonsa*, *Acartia hudsonica*, and *Eurytemora affinis*. Mysids undergo diel vertical migrations and are important food for many fish species in the Bay. Some taxa such as chaetognaths are not endemic to the bay but are transported in from the continental shelf. Various meroplankton such as larvae of decapods, bivalves, and gastropods become abundant at times. A striking seasonal change in the zooplankton community composition occurs in spring when large gelatinous zooplankton such as the ctenophore *Mnemiopsis leidyi* and (subsequently in summer) the scyphomedusa *Chrysaora quinquecirrha* (sea nettle) "bloom." *Mnemiopsis* blooms now appear earlier in the York River compared to 40 years ago, correlated to earlier warming in spring water temperatures. Humans may be influencing zooplankton populations in the York River via introduced species and eutrophication-induced hypoxia, as well as via input of contaminants. Future research priorities and monitoring needs include long-term monitoring of zooplankton communities, increased studies of the dynamics of microozooplankton and of gelatinous zoopankton, diel and seasonal cycles and grazing rates of some of the lesser studied groups (e.g., other than copepods), and use of new technology such as underwater digital video systems.

ABSTRACT

Introduction and Historical Perspective

The term "Plankton" means drifter (derived from the greek "planao" meaning "to wander"), thus the plankton are at the mercy of the currents more so than fish and other larger organisms. In the previous chapter the small plant drifters or phytoplankton were discussed; here we concentrate on the animal plankton or zooplankton. Zooplankton are a diverse group of heterotrophic organisms (ranging in size from unicellular flagellates one-hundredth of a millimeter in diameter to jellyfish a meter in diameter) that act to remove phytoplankton through their feeding, regenerate nutrients via their metabolism, and transfer energy to higher trophic levels. Zooplankton occupy a key position in pelagic food webs, as they transfer energy produced from phytoplankton through photosynthesis to higher trophic levels (fish) exploitable by humans. They are also key in determining the amount and composition of particles sinking to the benthos, which provides food for benthic organisms and contributes to burial of organic compounds.

Zooplankton can be grouped in many different ways, including size, habitat, depth distribution, length of planktonic life, and feeding mode. The size range is large, and can be very generally divided into microzooplankton (<200µm), mesozooplankton (200µm - 2 mm), and macrozooplankton (>2 mm). (Note- 1 µm =one-thousandth of one-millimeter.) Zooplankton are found in every aquatic habitat, from freshwater to estuarine to open ocean, and each habitat has a fairly distinct zooplankton fauna. Estuaries such as the York River are particularly interesting as the available habitat for zooplankton covers a wide salinity range. Zooplankton are also found at all depths in the water column, and some even reside in the sediments during the day and emerge into the water at night. Holoplankton spend their entire life cycle in the plankton, while meroplankton spend only a portion of their life cycle as members of the plankton. Meroplankton include many larval fishes, and larval stages of benthic invertebrates. The planktonic stage is generally used for dispersal of the young and is a very common life history strategy for estuarine invertebrates. What zooplankton feed on is not always clear, as it depends upon life stage, season, and food availability. But generally they can be grouped as herbivores which ingest only phytoplankton, omnivores which ingest both phytoplankton and zooplankton, and carnivores which ingest only other zooplankton, and detritivores which ingest detritus and bacteria.

Over the past 40 years, there have been relatively few studies specifically targeting zooplankton communities of the York River estuary and tributaries. The bulk of exploration to date has focused on the zooplankton of mainstem Chesapeake Bay, as part of several large-scale and multi-disciplinary surveys. For general multi-species time series reviews on microzooplankton and mesozooplankton from Chesapeake Bay see Brownlee and Jacobs (1987) and Olson (1987). Purcell et al. (1999a, 2001) and Condon and Steinberg (2008) review some of the gelatinous macrozooplankton. Grant and Olney (1983) and Grant (1977) examined mesozooplankton from the lower

Chesapeake Bay. Early studies in the York River transpired during the mid 1960–early 1970 period, with a research focus on taxonomy and distribution of copepods and gelatinous zooplankton (Calder, 1968, 1971; Burrell, 1972; Burrell and van Engel, 1976), as well as decapod larvae (Sandifer, 1973, 1975), and predation by ctenophores (Burrell and van Engel, 1976). Further investigation of York River mesozooplankton includes Price (1986). In 1987, the Chesapeake Bay Program (CBP) began sampling from four stations along the York River Estuary (WE 4.2–mouth of York River; RET 4.3–upper York; and TF 4.2 and RET 4.1–Pamunkey River), in conjunction with their long-term monitoring program of Chesapeake Bay and its tributaries. To date, the majority of zooplankton measurements have been collected from station WE 4.2, and data on species composition and abundance can be downloaded via the CBP website (http://www.chesapeakebay.net). One notable publication using this data set is that of Park and Marshall (1993) who described the distribution and seasonal abundance of microzooplankton at three of the four York River CBP stations.

DIVERSITY, NATURAL HISTORY, AND ECOLOGY OF MAJOR GROUPS OF ZOOPLANKTON IN THE YORK RIVER (AND ADJACENT CHESAPEAKE BAY)

Microzooplankton

The microzooplankton mostly include protozoans (single-celled animals), rotifers, and the larval stages of invertebrates. The unicellular protozoa are mostly classified by mode of locomotion, and consist of three major groups. These include the heterotrophic flagellates (~ 5-10 µm), that move with flagella (single or many) and feed on bacteria and detritus. They are important food for other zooplankton and ciliates. Some flagellates are larger (10's -100's µm), such as the heterotrophic dinoflagellates. The ciliates (most ~10-20 µm, some >200 µm) move using cilia that is present in all but a few forms sometime during their life cycle, and feed primarily on phytoplankton (Figure 1). Many ciliates have symbiotic algae from which they receive some of their nutrition. Titinnid ciliates live in a cup- or vase-shaped shell or "lorica" secreted by the cell (thus they are called loricate ciliates, as opposed to ciliates with no shell which are called aloricate or non-loricate) and are an important component of the microzooplankton in Chesapeake Bay (Figure 2). The sarcodines are ameobae, and move and feed using "pseudopodia." Sarcodines are omnivorous, and many have symbiotic algae too. While this group is important in coastal and open ocean waters, the main sarcodines found in the Chesapeake Bay belong to the family Difflugiidae (Sawyer, 1971) and they are mostly restricted to fresher water areas (Brownlee and Jacobs, 1987). Rotifers are small, multicellular animals containing a ciliated band around the head called the "corona" that is used for locomotion and feeding. They are most common in the fresher regions of the bay, and although patchy, can be highly productive and reach high densities in some regions of the Bay (Dolan and Gallegos, 1992). Other microzooplankton include the juvenile/larval stages of zooplankton such as copepods or other invertebrates.

Figure 1. Ciliate *Strombidium* sp. Photo by Matt Johnson.

Figure 2. Tintinnid ciliate. Photo by Matt Johnson.

Microzooplankton abundance in the lower Chesapeake Bay peaks in spring (March- April) and mid-summer to early fall (July-September), and reaches a minimum in winter (Dec-Jan) (Park and Marshall, 1993). This is a similar pattern seen in the rest of the Bay (Brownlee and Jacobs, 1987). The dominant groups of microzooplankton in the lower Bay are the ciliated protozoa (aloricate ciliates and tintinnids). Rotifers, copepod nauplii, and sarcodines are also important at times. A study of the lower Chesapeake Bay found non-loricate ciliates to represent 60%, tintinnids 33%, rotifers 4%, and nauplii larvae (mostly copepods) 3%, of the total microzooplankton composition (Park and Marshall, 1993). In the York River, the abundance of each of these groups was lowest in the tidal fresh region up-river, with numbers increasing in the meso- and polyhaline regions (Park and Marshall, 1993). The species diversity of tintinnids increases with decreasing salinity in the mainstem of the Bay (Dolan and Gallegos, 2001).

Mesozooplankton

Copepods

Copepods are small crustaceans approximately the size and shape of a grain of rice. They comprise the bulk of the zooplankton in the Chesapeake Bay (and all other estuarine and marine environments), and may be the most numerous multicellular animals on earth. The body is segmented, with a head with two pairs of antennae and 4 pairs of mouthparts, a mid-body with swimming legs, and a posterior that lacks appendages. They are generally omnivorous, but some are more strictly herbivorous or carnivorous, as well detritivorous. Copepods have separate sexes, and 12 stages of development (first six stages are naupliar larvae, and the last six are copepodite stages– the last of which is the adult). These early juvenile stages are considered part of the microzooplankton community described above.

The dominant copepod species in the Chesapeake Bay are the calanoid copepods *Acartia tonsa*, *Acartia hudsonica* (formerly *Acartia clausii*), and *Eurytemora affinis* (Heinle, 1966, Brownlee and Jacobs, 1987, Olson, 1987). In the lower polyhaline portion of the bay, the summer copepod assemblage is dominated by *Acartia tonsa* (Figure 3), and in winter there is a shift to *Acartia hudsonica* (Brownlee and Jacobs, 1987). In the upper mesohaline portion of the York River (station RET 4.3, CBP), *Acartia* spp. abundance peaks in August and *Eurytemora* peaks in March /April. However, while the lower York also experiences a summer *Acartia* bloom there is no winter *Eurytemora* peak (station WE 4.2, CBP, Steinberg and Brush, unpublished data). This is consistent with what is found in the rest of the lower polyhaline region of the mainstem bay, where numbers of *Eurytemora affinis* are much reduced compared to the upper, mesohaline, mainstem bay. In the lower York, *Pseudodiaptomus coronatus* can also be very abundant in summer (Price, 1986). *Acartia* exhibits diel vertical migration, with densities substantially higher in the surface waters at night in the lower York (Price, 1986) and elsewhere in the Bay (Cuker and Watson, 2002). The next most abundant copepods in the York River are the cyclopoid copepods *Oithona* spp. There are more than 60 species of copepods reported in the York River (see Appendix), but the seasonal and interannual cycles of most have yet to be investigated.

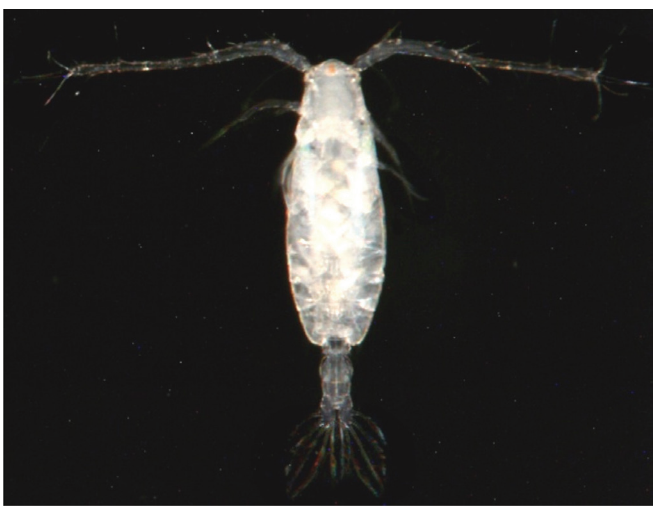

Figure 3. Copepod *Acartia tonsa*.

Cladocera

The cladocera are most abundant in freshwater, with only about 10 species that are truly marine planktonic, and in freshwater their ecological role is equivalent to copepods in marine systems. Thus cladocera are numerically and ecologically more important up-river. Cladocera have a flat body covered by a carapace, with large, compound eyes that can take up to one-third of the body. The 2nd antennae are used for swimming. Cladocera reproduce sexually or parthenogenically, and have a brood pouch inside their carapace from which young are released. They are filter feeders and generally omnivorous, consuming phytoplankton, microzooplankton, and copepod eggs.

In the Chesapeake Bay, cladocera are most abundant in warmer months and commonly occur at the extreme geographic/ salinity ranges of the bay. Freshwater cladocera can make up >50% of the zooplankton in the freshwater tributaries of the bay (Brownlee and Jacobs, 1987), while other true estuarine species, such as *Podon polyphemoides* which peaks in May, occasionally proliferate in the lower, polyhaline portion of the bay, sometimes extending the length of the estuary (Bosch and Taylor, 1967, 1973). In the tidal fresh Mattaponi tributary of the York, *Bosmina* is the most common genus and peaks in spring (April/May) (J. Hoffman, pers. comm.), while *Podon* peaks at the mouth of the York in July (CBP; Steinberg and Brush, unpublished) (Figure 4).

Figure 4. Cladocera *Podon* sp.

Mysids, isopods, and amphipods

These crustaceans belong to a group (the pericarids) that shares the diagnostic feature of brooding their young in a pouch from which they hatch as miniature adults. Mysids look much like shrimp, however they have a 'statocyst' or balance organ on their tail, which can be used to distinguish them from shrimp (Figure 5). Mysids in the York River and Chesapeake Bay (mainly *Neomysis americana*) remain near the bottom during the day and swim up into the water column at night (Price, 1986, Cuker and Watson, 2002), as is typical of this group. Mysids are omnivorous and prey on other zooplankton such as copepods (Fulton, 1982) and phytoplankton. Mysids are important food for many fish species in the Bay, including American shad, striped bass, white perch, and flounder (e.g., Walter and Olney, 2003). We know little about mysid distribution and seasonal cycles, as most studies of plankton in the Bay have sampled only in the daytime. Amphipods are familiar to most people as the small 'beach hoppers' on dead algae found on the beach. Planktonic amphipods feed on dead phytoplankton or other detritus, as well as on other animals. Amphipod bodies appear compressed laterally, as opposed to the related isopods, which are flattened dorso-ventrally. Most isopods are strictly benthic, and thus they are uncommon in the plankton. There is little available information on amphipods and isopods in York River plankton, however in the adjacent lower Bay amphipods are dominated by the species *Gammarus mucronatus* in surface waters, and isopod densities are very low (Grant and Olney, 1983).

Figure 5. Mysid

Chaetognaths

The chaetognaths or "arrow worms" are abundant and voracious predators in the plankton. They eat copepods, smaller chaetognaths, fish, and crustacean larvae. These transparent plankton have both lateral fins and tail fins, as well as large, spiny, chitinous hooks on their head used to capture and stun their prey. Chaetognaths are not endemic to the bay but are transported in from the continental shelf. The polyhaline portion of the bay near the mouth of the York River sees several species, such as the annual fall invasion of *Sagitta tenuis* (Grant, 1977).

Meroplankton and demersal zooplankton

At certain times of the year and in different salinity regimes, various meroplankton such as crab or other decapod larvae (Figure 6), bivalve (clam) and gastropod (snail) larvae, naupliar and cyprid stages of barnacles, and polychaete worm larvae (Figure 7) become numerically important in the Bay (Brownlee and Jacobs, 1987, Olson, 1987, Grant and Olney, 1983) and in the York River (e.g., Sandifer, 1973). Some of these are demersal zooplankton–residents of the benthos that emerge into the water column, especially at night. Decapod larvae are common in the York River, especially downriver. One of the most common species of decapod larvae include the Sand Shrimp, *Crangon septemspinosa*, which was found to be responsible for winter peaks in decapod abundance, and there are also a number of important crab larvae (Sandifer, 1973, 1975). Many species of decapod larvae tend to be more abundant near the bottom where net transport is upstream, likely as a mechanisms for retention within the estuary (Sandifer, 1973, 1975). In the lower Chesapeake Bay, decapod larvae become dramatically more diverse in summer months *vs.* winter (Grant and Olney, 1983). A number of bivalve and gastropod larvae occur in the lower bay, and naupliar and cyprid stages of barnacles have been noted to occur in higher densities at the surface at dawn and dusk in the lower Bay (Grant and Olney, 1983). Most polychaetes are benthic, but the larval stages of benthic polychaetes are sporadically abundant in Chesapeake Bay plankton. These segmented, bristled worms swim and can hold on to prey using their parapodia (modified 'feet'). The planktonic polychaetes are normally carnivorous or detritivorous, and may have a proboscis or jaw that everts out from the head to capture prey. The most abundant and widely distributed polychaetes in summer lower Bay samples reported by Grant and Olney (1983) were Spionid larvae.


Figure 6. Decapod (crab) larva


Figure 7. Polychaete larva

Other rare groups

Other groups such as the ostracods, also called "seed or clam shrimps," are primarily benthic in the estuarine environment, and thus rarely found in plankton samples in the York or adjacent Bay waters. Pelagic, gelatinous tunicates such as larvaceans and doliolids are also rare in estuaries, but occasionally occur in samples in the lower Bay (Grant and Olney, 1983).

Large gelatinous zooplankton

Gelatinous zooplankton is a term commonly used to describe plankton that are made up of primarily "soft," jelly-like tissue. Despite their large size, gelatinous zooplankton are not strong swimmers so their movements are primarily determined by the currents and are thus referred to as plankton. In the York River estuary, the gelatinous fauna is relatively species rich compared to other coastal regions of the world, with over 25 species. A striking seasonal change in the zooplankton community composition of the tributaries and the main stem of the mesohaline and polyhaline portions of the bay occurs in the summer when large gelatinous zooplankton "bloom" (Condon and Steinberg, 2008).

Ctenophores

Ctenophores or comb jellies are the largest animal to move by cilia, and have eight rows of 'combs' made of fused macrocilia that they use to swim (Figures 8 and 9). Some have tentacles loaded with sticky cells called colloblasts that are used to capture food. Others, such as the lobate ctenophores, use a pair of oral lobes coated with sticky mucus to trap prey items upon contact. Ctenophores are a very bioluminescent group, and many of the larger bioluminescent flashes one might see at night in the Bay in the wake of a boat come from them. Ctenophores are carnivorous and prey upon copepods (Condon and Steinberg, 2008), larval fish and crustaceans, and in some cases other ctenophores.


Figure 8. Ctenophore *Mnemiopsis leidyi*


Figure 9. Ctenophore *Beroë ovata*

Larval and smaller ctenophores also consume microzooplankton and small protozoans (Stoecker *et al.*, 1987a; Sullivan and Gifford, 2004). They have high predation rates and can drastically deplete the abundance of other planktonic species. All ctenophores are hermaphrodites and capable of self-fertilization. Sexual reproduction occurs in the water column (i.e., broadcast spawners), after which miniature (1–5 mm length) cydippid larvae form that grow rapidly into adults (>20mm length).

The dominant ctenophore in the York River and Chesapeake Bay is the lobate ctenophore, *Mnemiopsis leidyi* ('sea walnut') (Figure 8). In the York River, *M. leidyi* persists throughout the year, with two distinct bloom periods with large spikes in the population (Condon and Steinberg, 2008). During the summer months (May–August), a large biomass of ctenophores is distributed along the entire length of the estuary, occurring in salinities of 6–27.5 psu (Burrell and van Engel, 1976; Figure 10). At these times, comparable numbers of *Mnemiopsis* are also observed in the mesohaline and polyhaline regions of Chesapeake Bay (Burrell, 1968, Purcell *et al.*, 1994a, CBP). Interestingly, temperature does not limit the ability of *M. leidyi* to grow rapidly, as blooms also occur in the lower York River (salinities >15 psu) between December–March (Burrell and van Engel, 1976; Condon and Steinberg, 2008). It is unclear whether similar abundances appear in the mainstem Chesapeake Bay during the winter. The next most abundant ctenophore in the York River is *Beroë ovata* ('pink sea jelly') (Figure 9). This football-shaped ctenophore lacks both tentacles and feeding lobes and consumes other ctenophores, particularly *M. leidyi*. Little is known about *B. ovata* feeding but some individuals can consume as many as seven *M. leidyi* at one time (Burrell, 1972). *Beroë ovata* is present mainly in the lower York River from August to early December (Burrell, 1972; Burrell and van Engel, 1976; Condon and Steinberg, 2008; Figure 10), and due to their cannibalistic behavior, *B. ovata* greatly reduces the biomass of *M. leidyi* when both species coexist. As a result, the highest numbers of *M. leidyi* in the York River during the late summer–fall period are found outside the range of *B. ovata* (Burrell and van Engel, 1976). One other ctenophore that can be found in the York during the spring is the tentaculate ctenophore or sea gooseberry, *Pleurobrachia* sp., although in general it is rare.

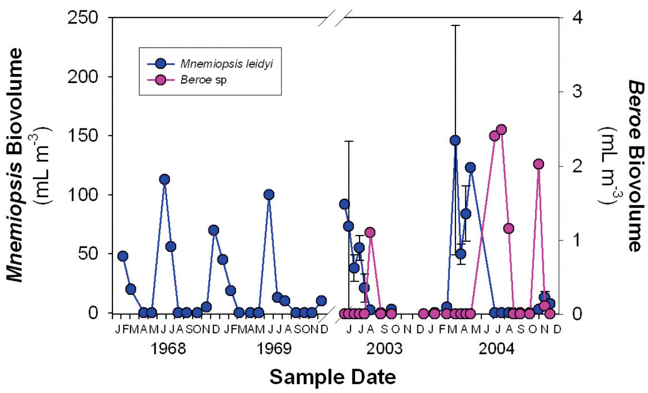

Figure 10. Seasonal cycle of ctenophores in the York River. (Data from Burrell and van Engel, 1976, and Condon and Steinberg, 2008)

Scyphomedusae

Scyphomedusae (or Scyphozoan medusae), known locally as sea nettles or jellyfish, are notorious to Chesapeake Bay, primarily due to the stings they inflict to sea bathers each summer, and for their ability to form swarms. Medusae are mainly carnivorous and are major consumers of copepods, larval fish and crustaceans, ctenophores and other gelatinous zooplankton. Prey are caught using tentacles containing harpoon-like, stinging cells called nematocysts. Scyphozoan reproduction is complex, often with both a planktonic, sexual adult medusa stage, and a benthic, asexual polyp stage.

The most common scyphomedusan in the York River and lower Chesapeake Bay is the sea nettle, *Chrysaora quinquecirrha* (Figure 11), which is found along the entire east coast of the USA. *Chrysaora* medusae are present from late May through October, with a population peak any time during July–September (Cargo and Schultz, 1966, 1967, Cargo and King, 1990; Condon and Steinberg, 2008).

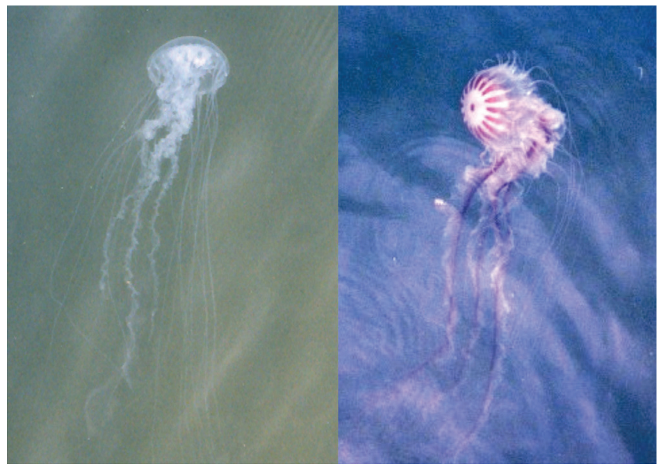

Figure 11. Sea nettle *Chrysaora quinquecirrha*. Two color morphs exist in the lower Chesapeake Bay, the more common white variety (left) and a less common red-striped variety (right).

Seasonal and interannual variability in medusae abundance is a function of water temperature and salinity, as well as zooplankton prey abundance (Cargo and King, 1990, Purcell *et al.*, 1999a). Using these variables and other data, NOAA have developed a sea nettle model which forecasts the distribution of medusae throughout Chesapeake Bay and its tributaries, which can be viewed at the following website: http:/www.coastwatch.noaa.gov/seanettles. In the mesohaline Chesapeake Bay and York River estuary, *C. quinquecirrha* medusae are major predators of *M. leidyi* ctenophores (Purcell and Cowan, 1995; Condon and Steinberg, 2008). The creeks and tributaries of the York River may be important nursery grounds for *C. quinquecirrha*, where large amounts of suitable hard substrate such as oyster shells/reefs exist, on which polyps develop. Two color morphs of *Chrysaora* exist in the lower Chesapeake Bay, the more common white variety and a less common red-striped variety (Figure 11), and these varieties probably represent the same species (K. Bayha, pers. comm.).

Another scyphomedusan abundant at times in the York River is the moon jelly, *Aurelia* sp. (Figure 12). Moon jellies are present in the polyhaline regions of the lower York River and Chesapeake from June–July when they can form large

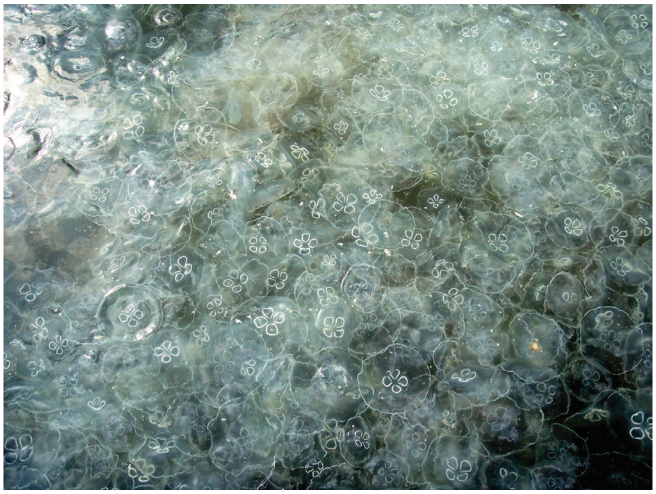

Figure 12. Moon jelly *Aurelia* sp. bloom in Mobjack Bay at the mouth of York River. Photo courtesy of Scott Kupiec.

swarms or aggregations (Condon and Steinberg, 2008) (Figure 12), usually determined by local hydrographic conditions such as fronts (Graham *et al*., 2001). In the winter months (January–March) the Lion's Mane jellyfish, *Cyanea* sp., can also be found in the lower York River and Chesapeake Bay (Burrell, 1972; Condon and Steinberg, 2008). This winter jelly has received little attention and consequently virtually nothing is known of the ecology and impact of *Cyanea* medusae in the York River. The cannonball jelly, *Stomolophus meleagris*, and the mushroom cap jelly, *Rhopilema verilli*, are two additional species found in the lower York River and Chesapeake Bay but both are infrequently seen.

Hydromedusae

Hydromedusae (or Hydrozoan medusae) are small (0.1mm–5mm), inconspicuous jellies, and are represented in the York River by over 20 species (Appendix I; Calder 1968, 1971). Hydromedusae are among the best described plankton groups in the world (Purcell *et al.*, 1999a), yet they have received little attention in the York River estuary. Their life cycle is similar to scyphomedusae except their benthic stage (known as hydroids) is morphologically different, and in many species the medusa stage is brief. Hydromedusae are primarily carnivorous, consuming copepodites, nauplii and other microzooplankton, and during the fall hydromedusae may be key predators in the pelagic food web in southern Chesapeake Bay (Purcell *et al.*, 1999a).

One of the most conspicuous hydromedusae in the York River and Chesapeake Bay is *Nemopsis bachei*. This euryhaline hydromedusae is found from the lower reaches of the York River and southern Chesapeake Bay (Calder, 1971) to the oligohaline regions near the Pamunkey River (< 6 psu). *Nemopsis bachei* is present in the York River throughout the year with population peaks in late spring, and during fall and early winter (September–January). During spring, *N. bachei* is the most abundant gelatinous zooplanktivore in the mesohaline Chesapeake Bay, where they consume primarily *Acartia tonsa* copepodites, and nauplii (Purcell and Nemazie, 1992), and may be partially responsible for poor fish recruitment during red drum spawning season (Cowan *et al.,* 1992). Various other hydromedusae, including *Liriope tetraphylla*, *Clytia* sp. (cf. *Clytia edwardsi*), and *Cunina* sp. (cf. *Cunina octonarina*), also appear in high numbers during October, particularly in southern Chesapeake Bay and the lower York River (Burrell, 1972; Purcell *et al.*, 1999a).

TROPHIC STRUCTURE AND ENERGY FLOW

Microzooplankton are important grazers of bacteria and small phytoplankton in the Chesapeake Bay, and are themselves important food for larger grazers such as copepods. In the Bay, phytoplankton composition changes from mainly diatoms during spring blooms to dominantly smaller cells during non-bloom periods (Ray *et al.*, 1989). These smaller cells cannot be consumed by mesozooplankton directly. Thus the microzooplankton/ microbial food web is important during much of the year and an important link for transfer of energy to higher trophic levels. Microzooplankton are important food for copepods and other grazers in Chesapeake Bay. The copepod *Acartia tonsa* feeds on ciliates and rotifers at rates higher than that for phytoplankton, an indication that microzooplankton may be an important part of the copepod diet (Stoecker and Egloff, 1987). Copepod predation can also affect diversity of some groups such as tintinnids (Dolan and Gallegos, 2001). Microzooplankton are also important food for larval ctenophores (Stoecker *et al.,* 1987a, Sullivan and Gifford, 2004) and are fed upon by the jellyfish *Aurelia aurita* (Stoecker *et al.,* 1987b). Copepods are the key grazers of phytoplankton in Chesapeake Bay, and can remove a substantial percentage of the daily phytoplankton production (White and Roman, 1992). However, estimates of Bay-wide grazing by microzooplankton and mesozooplankton combined indicate that on average zooplankton remove less than one-third of the phytoplankton biomass daily, thus much of the phytoplankton is not grazed but becomes fuel for bacterial metabolism (Sellner and Jacobs, 1993) or sinks to the benthos.

Because bloom-forming gelatinous zooplankton such as ctenophores and sea nettles are voracious consumers of mesozooplankton (primarily copepods) (Condon and Steinberg, 2008) and larval fish (Purcell, 1992, Cowan and Houde, 1993, Purcell *et al*., 1994a,b), they are extremely important in shaping plankton and fish communities in the summer months (Baird and Ulanowicz, 1989). In the Chesapeake Bay *M. leidyi* is most abundant between June and September. *Chrysaora quinquecirrha* medusae consume ctenophores and can control *M. leidyi* populations in Chesapeake Bay (Feigenbaum and Kelly, 1984, Purcell and Cowan, 1995; Condon and Steinberg, 2008). Thus the reduction of ctenophore populations usually coincides with the seasonal appearance of *C. quinquecirrha* (in the lower bay the predatory ctenophore *Beroë* occurs in early fall and may contribute to mortality of *M. leidyi*; Burrell, 1968). Burrell and van Engel (1976) noted, however, that *Chrysaora* did not reduce ctenophores in the York River. When *M. leidyi* population growth goes unchecked by predation, zooplankton populations can be depleted (Kremer 1994). Thus, the predation of medusae on ctenophores can lead to complex food web changes that can ultimately reduce the mortality of other zooplankton and icthyoplankton (Feigenbaum and Kelly, 1984, Purcell *et al.*, 1991, Purcell and Cowan, 1995). This "trophic cascade" can result in increases in numbers of other zooplankton (e.g., copepods).

CHANGES OVER TIME

Few studies have examined long-term trends of zooplankton communities in the York River and mainstem Chesapeake Bay. Using data collected from the main stem stations of the CBP, Kimmel and Roman (2004) found no overall long-term trends for the copepods *Eurytemora affinis* and *Acartia tonsa* over a 16-year period, but concluded freshwater input and top-down control by gelatinous predators were partial factors in shaping copepod populations. More recently, Purcell and Decker (2005) correlated *Chrysaora* scyphomedusae abundance with climatic conditions in the mesohaline Chesapeake Bay, and found high medusae densities during 1987–1990, which followed a year of high salinity, warm temperature, and high solar irradiance. On a larger time scale, the North Atlantic Oscillation Index was inversely correlated with medusae numbers from 1960–1995 (Purcell and Decker, 2005). Similarly, Condon and Steinberg (2008) show that *Mnemiopsis* blooms now appear earlier in the York River estuary compared to 40 years ago, and correlate this temporal shift to the warming in spring water temperatures and the earlier release of temperature limitation on ctenophore reproduction. Whether similar trends have occurred in other York River zooplankton is yet to be determined and would necessitate continual long-term monitoring of zooplankton throughout the year.

HUMAN INFLUENCES ON ZOOPLANKTON IN THE YORK RIVER

Introduced Species

Zooplankton are easily introduced into estuarine systems because many species are tolerant of a wide range of salinity and temperature and have life cycle stages that are resilient or remain dormant (e.g., encyst) in unfavorable conditions. A good example is the invasion of the ctenophore, *M. leidyi*, in Black Sea, which ironically was likely introduced from Chesapeake Bay (Purcell *et al.*, 1999a, 2001). Subsequent population explosions of *Mnemiopsis* impacted greatly on copepod and fish populations and resulted in the closure of many commercial fishing operations in that region.

While many examples probably exist, there are few records of introduced zooplankton species to the York River and lower Chesapeake Bay. One example, however, is the inconspicuous hydrozoan, *Moerisia lyonsi*, present in the oligohaline regions of the York River during summer (Calder, 1971). *Moerisia* is thought to have been introduced from Egypt (Calder and Burrell, 1966; Purcell *et al.*, 1999b), however the long-term ecological impact of this species introduction is unknown. As *Moerisia* consume copepod adults and nauplii (Purcell *et al.*, 1999b), and probably fish larvae and eggs too, copepod abundance and fish recruitment could be affected. Further research into the feeding ecology, distribution and seasonal occurrence of *M. lyonsi* is needed in order to fully understand the impact of these hydrozoans (Purcell *et al.*, 1999b).

Eutrophication

As discussed in the paper by Reay in this Special Issue, anthropogenic eutrophication and water quality is a major issue in the Chesapeake Bay. However, whether there is direct link between eutrophication and York River zooplankton is purely speculative (Purcell *et al.*, 1999a), because there is a paucity of information on zooplankton distributions prior to 1960 (Arai, 2001) when waters were relatively pristine.

Hypoxia

One major influence of eutrophication is increased bottom water hypoxia (< 2 mg O_2 l^{-1}), or in extreme circumstances anoxia (< 0.5 mg O_2 l^{-1}), resulting in an increase in oxygen deplete bottom waters in many regions of Chesapeake Bay and the York River (Taft *et al.*, 1980, Sanford *et al.*, 1990). Hypoxia can have both positive and negative effects on zooplankton survival and behavior. For example, copepod and ichthyoplankton survival, and hatching success of copepod eggs, are very low under hypoxic conditions (Roman *et al.*, 1993; Breitberg *et al.*, 1997; Decker *et al.*, 2004), and *Acartia* ceases its diel vertical migrations making these copepods vulnerable to predation by gelatinous zooplankton (Roman *et al.*, 1993). In contrast, gelatinous zooplankton such as *C. quinquecirrha* medusae and polyps, and *M. leidyi,* are tolerant of hypoxia and thus theoretically have the potential to predominate under these conditions (Purcell *et al.*, 1999a; Condon *et al.*, 2001; Decker *et al.*, 2004). However in the mesohaline Chesapeake Bay and the York River these gelatinous predators appear to avoid these waters (Burrell and van Engel, 1976; Purcell *et al.*, 1999a), perhaps in response to the lack of food below the pycnocline. Further increases in hypoxia, as a direct result of eutrophication, has the potential to significantly impact zooplankton populations in the York River and thus alter the planktonic food web as a whole.

Contaminants

Assessing the degree to which contaminants affect zooplankton populations in the York River is difficult due to the lack of data from this estuary. However, as evidenced from Chesapeake Bay, it is clear that exposure to contaminants can severely impact zooplankton, particularly copepods and decapods that are sensitive and vulnerable to these pollutants (Bradley and Roberts, 1987).

Heavy metals (e.g., mercury) and pesticides (e.g., tributyltin) are two contaminant groups that pose the greatest risk to estuarine zooplankton. Their most drastic effect is death but other side effects occur, including reduced fecundity and longevity, stress and altered feeding behavior (Bradley and Roberts, 1987). Bioaccumulation of contaminants is another major problem that can cascade throughout the food chain, but this depends upon the rate of biodegradation, uptake kinetics and bioavailability of the contaminants (Bradley and Roberts, 1987). For example, in the mesohaline Chesapeake Bay, *Acartia* copepods bioaccumulate hydrophobic organic contaminants (HOC) associated with their food, but the HOC concentration is dependent on the particle size consumed (Baker *et al.*, 1994; Roman, 1994).

The York River is also home to large industry including the BP Amoco oil refinery and Virginia Electric and Power plant at Yorktown, and the West Point paper mill. Industries like power plants are major sources of heat and biocides or oxidants, like chlorine, to waterways they utilize (Bradley and Roberts, 1987). Studies into the effects of these two contaminants from Chesapeake Bay show that chlorines have a greater impact on adult and larval copepod survival than temperature (Olson, 1987).

Dredging occurs frequently in the York River to accommodate both commercial and military traffic, and while it difficult to test in the field, the potential impact on zooplankton is large in areas where toxic sediments have been disturbed or deposited (Bradley and Roberts, 1987).

RESEACH PRIORITIES AND FUTURE MONITORING NEEDS

Long-term monitoring of zooplankton communities is needed to allow us to predictively model the ecosystem of the York River. Zooplankton monitoring data is needed to increase our understanding of factors affecting fish recruitment and to support ecosystem-based fisheries management. It is also needed to examine shifts in zooplankton abundance and community composition due to effects of introduced species, increases (or reduction) in nutrients, or a change in watershed land use. Compared to the main stem Chesapeake Bay and some of the more northern tributaries of the Bay, zooplankton in the York River have been little studied. While the CBP has provided a basis for understanding interannual and seasonal abundance of the major zooplankton groups, many gaps still remain.

There are only a handful of published studies on the microozooplankton community in the York River. Members of this diverse community are rarely identified to the species level, and we know little about their trophic structure and next to nothing about their feeding rates in the York River. As the microzooplankton must certainly be major consumers of primary production in the estuary, especially during the summer months, more work is needed in characterizing this community and measuring their grazing rates and impact on the phytoplankton community.

While diel and seasonal cycles and grazing rates of some of the most common mesozooplankton such as *Acartia tonsa* are known, we still lack information on the multitudes of other species. For example, historically most sampling has occurred during the day. Many species, such as mysids and demersal zooplankton, are more abundant in surface waters at night, and feeding rates can be higher at night as well. These and other crustacean zooplankton are important prey items for larval menhaden and bay anchovy, however estimates of their abundance are poor. Future monitoring studies should thus include paired day and night sampling. Another example is that little is still known about the dynamics of larval invertebrates in the York, information which is needed to help us understand benthic invertebrate community dynamics.

Dynamics of gelatinous zooplankton, especially that of the larger medusae (sea nettles, moon jellies), is still poorly known and sampled in the York. More sampling of the tributaries of the York River is needed to investigate early life history stages of medusae. We also know nothing of the fate of these remarkable gelatinous zooplankton blooms–do they sink out or are they consumed? While plankton nets sample the ctenophores adequately, sampling of the larger medusae is more difficult. Larger nets are needed but often prohibitive as monitoring normally takes place off of smaller boats from which such nets are difficult to deploy. Alternatively, new technology such as camera systems that can see large volumes of water could be used to obtain reliable estimates of the abundance and distribution of this very important component of the zooplankton community.

New technology should be an important part of future monitoring studies. Olney and Houde (1993) used silhouette photography with some success to monitor zooplankton communities in the Chesapeake Bay. Another possibility is the video plankton recorder or VPR. The VPR is an underwater digital video microscope designed for high resolution imaging of plankton (Davis *et al.*, 1996). Upon retrieval, data and images can be analyzed by an image recognition software package that automatically identifies and counts organisms. If instruments such as the VPR can be modified for use in high particle load environments such as the York River, there is potential to map zooplankton species abundance over large spatial scales.

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APPENDIX

Species List of Zooplankton for the York River Estuary

The catalog of species found within the York River are recorded in chronological order with the initial reference listed first and the most recent last.

Key for references:
1 = Park and Marshall, 1993
2 = Burrell, 1972
3 = Burrell and van Engel, 1976
4 = Sandifer, 1973
5 = Sandifer, 1975
6 = Price, 1986
7 = Chesapeake Bay Program (data from Stations CB 6.4, WE 4.2, RET 4.1 and 4.3, and TF 4.2)
8 = Calder, 1968
9 = Calder, 1971
10 = Calder and Burrell, 1966
11 = Purcell, Malej and Benovic, 1999
12 = Grant and Olney, 1983

+ indicates species predominately found in southern Chesapeake Bay
* indicates species predominately found in the Pamunkey River and the freshwater tributaries.
^ indicates species is non native to the York River
R indicates species are rare or infrequently observed
L indicates species represented in plankton by larval or egg stage

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<u>Phylum Ciliophora (Ciliates)</u>

Class Litostomatea
Order Haptorida
Didinium sp. — 1

Class Spirotrichea
Order Stombidiida
Strombidium sp. — 1

Order Choreotrichida
Strobilidium sp. — 1

Order Tintinnida (Loricate ciliates)
Eutintinnus sp. — 1
Tintinnopsis sp. — 1
Tintinnidium sp. — 1

<u>Phylum Foraminifera</u>

Globorotalia sp. — 7

<u>Phylum Rotifera</u>

Brachionus sp. — 1
Branchionus calyciflorus — 7
Branchionus havanaensis — 7
Filinia sp. — 1
Keratella sp. — 1
Synchaeta sp. — 1
Trichocerca sp. — 1

<u>Phylum Cnidaria</u>

Class Scyphozoa (True jellyfish or Scyphomedusae)
Order Semaeostomeae
Aurelia sp. (Moon jelly) — 2,7
Chrysaora quinquecirrha (Sea nettle) — 2,3,7
Cyanea sp. (Lion's mane jelly) — 2

Order Rhisostomeae
Rhopilema verrilli[R] (Mushroom cap jelly) — unpub. data
Stomolophus meleagris[R] (Cannonball jelly) — unpub. data

Class Hydrozoa (Hydromedusae)
Order Anthomedusae
Bougainvillia rugosa — 8,9,7
Dipurena strangulate — 8,9
Ectopleura dumortieri — 8,9
Halocordyle tiarella — 8,9
Hydractinia arge — 8,9
Hydra carnea — 7
Linvillea agassizi — 8,9
Moerisia lyonsi ^ — 8,9,10
Nemopsis bachei — 8,7,9
Podocoryne minima — 8,9
Proboscidactyla ornate — 8,9
Rathkea octopunctata — 8,9
Sarsia tubulosa — 8,9
Turritopsis nutricula — 8,9

Order Leptomedusae
Aglantha digitale — 8,9
"*Campanulina*" sp. — 8
Clytia edwardsi — 8,9,11
Cunina octonarina — 8,9,11
Eucheilota ventricularis — 8,9,7
Lovenella gracilis — 8,9
Liriope tetraphylla — 8,9,11
Obelia spp. — 8,9
Phialicium carolinae — 8,9

Phylum Ctenophora (Comb jellies)

Class Tentaculata

Order Lobata

Mnemiopsis leidyi (Sea walnut)	2,3,7

Order Cydipidda

Pleurobrachia sp. (Sea gooseberry)	7

Class Nuda

Order Beroida

Beroe ovata (Pink sea jelly)	2,3,7

Phylum Platyhelminthes (Flat worms)

Turbellaria sp.	7

Phylum Chaetognatha (Arrow worms)

Sagitta tenuis	2
Sagitta elegans	2,7
Sagitta enflata	7

Phylum Polychaeta (Bristle worms)

Autolytus sp.	7
Polydora ligni	7
Polydora sp.	2

Phylum Phoronida (Horseshoe worms)

Phoronis architecta	7
Phoronis sp.	7

Phylum Mollusca[L]

Class Bivalvia

Crassostrea virginica (American oyster)	7
Mercenaria mercenaria (Quahog or Hard clam)	unpub. data
Mytilus edulis (Blue mussel)	7

Class Cephalopoda

Loligo sp.	7
Lolliguncula brevis	7

Phylum Arthropoda

Subphylum Crustacea

Class Maxillopoda

Order Siphonostomatoida

Caligus sp.	7

Subclass Copepoda (Copepods)

Order Calanoida (Calanoid Copepods)

Acartia hudsonica	2,3,7
Acartia longiremis	7
Acartia tonsa	2,3,7
Calanus finmarchicus[+]	2,7
Centropages furcatus[+]	2,7
Centropages hamatus	2,3,7
Centropages typicus	2,7
Diaptomus sp.	7
*Eucalanus pileatus**	2,7
Eurytemora affinis	2,7
*Eurytemora americana**	2,7
Eurytemora hirundoides	7
Labidocera aestiva	2,3,7
*Mecynocera clause**	2
Metridia lucens	7
Paracalanus crassirostris	2,7
Paracalanus fimbriatus	7
*Paracalanus indicus**	2,7
*Paracalanus quasimodo**	2
Pseudocalanus minutus	2,7
Pseudocyclops sp.*	2,7
Pseudodiaptomus coronatus	2,3,7
Rhincalanus nastus[R]	7
Temora longicornis	2,7
*Temora stylifera**	2,7
*Temora turbinat**	2,7
*Tortanus discaudatus**	2,7

Order Cyclopoida (Cyclopoid copepods)

Acanthocyclops vernalis	7
*Corycaeus amazonicus**	2,7
Corycaeus speciosus	7
Corycaeus venustus	7
Cyclops vernalis	2,7
Diacyclops thomasi	7
Ectocyclops phaleratus	7
*Eucyclops agilis**	2,7
Halicyclops fosteri	2,7
*Hemicyclops adherans**	2
*Leptinogaster major**	2
Mesocyclops edax	2,7
*Mesocyclops leukarti**	2
Mesocyclops obsoletus	7
Oithona brevicornis	2
Oithona colcava	7
Oithona similis	2
*Oncaea mediterranea**	2,7
Paracyclops affinis	7
Paracyclops sp.	7
Saphirella sp.	7
Troprcyclops sp. (cf. *T. prafinus mexicanus*)	7

Order Harpacticoida (Harpacticoid copepods)

*Alteutha oblongata**	2
Canuella canadensis	2
*Canthocamptus**	7
Canuella elongata	7
Clytemnestra rostrata[+]	7
Diosaccus tenuicornis	7
*Euterpina acutifrons**	2,7
Paralaophonte brevirostris	7
Harpacticus chelifer	7
Harpacticus gracilis	7
Tisbe furcata	7
Zausodes arenicolus[*,R]	7

Order Poecilostomatoida

Ergasilus cerastes	2
Ergasilus versicolor	7
Farranula gracilis	2

Class Branchiopoda

Order Cladocera (Cladocerans)

_Alona guttata_*	7
_Alona quadrangularis_*	7
_Alonella rostrata_*	7
Bosmina coregoni maritime	7
Bosmina longirostris	7
_Ceriodaphnia reticulata_*	7
_Chydorus_*	7
_Daphnia ambigua_*	7
_Daphnia longispina_*	7
_Daphnia pulex_*	7
Diaphanosoma brachyurum	7
_Eurycercus lamellatus_*	7
Evadne nordmanni	7
Evadne tergestina	7
Holopedium sp.	7
_Ilyocryptus spinifer_*	7
_Latonopsis fasciculate_*	7
_Leptodora kindtii_*	2,7
_Leydigia quadrangularis_*	7
_Moina brachiata_*	7
Penilia avirostris	7
Pleuroxus striatus[R]	7
_Pseudosida bidentata_*	7
Scapholeberis kingi[*,R]	7
_Simocephalus_*	7
_Sida crystalline_*	7
Podon intermedius	7
Podon polyphemoides	7
Podon sp.	2

Class Malacostraca

Order Decapoda (Crab and shrimp larvae)[L]

Acetes americanus	7
Alpheus cf _heterochaelis_[+,R]	4,7
Alpheus normanni[+,R]	4,7
Callinassa cf. _atlantica_[+]	4,7
Callianassa cf. _biformis_[R]	4,7
Callinectes sapidus (Blue crab zoea)	2,4,5,7
Cancer irroratus[+]	4,5,7
Crangon septemspinosa (Sand shrimp zoea)	2,4,5,7
Dissodactylus mellitae[+,R]	4
Emerita talpoida[+] (Sand crab larvae)	4,7
Euceramus praelongus	4,7
Eurypanopeus depressus [R]	4,7
Hexapanopeus augustifrons	4,5,7
Hippolyte pleuracantha	4,5,7
Lepidopa cf. _websteri_[+]	4,7
Libinia spp.[R]	4,7
Libinia emarginata	7
Lucifer faxoni[+]	4,7
Macrobrachium ohione	7
Naushonia crangonoides[+]	7
Neopanope sayi (cf. _N. texana sayi_)	4,5,7
Ogyirides limicola	4,5,7
Ovalipes ocellatus	4,5,7
Pagurus longicarpus	4,7
Pagurus pollicaris[+,R]	4,7
Palaemonetes spp.	2,4,5,7
Palaemonetes pugio	7
Panopeus herbstii	4,7
Penaeus spp.[+,R]	4
Penaeus aztecus	7
Pinnixa chaetopterana	5,7
Pinnixa cylindra[+]	4,7
Pinnixa sayana	4,5,7
Pinnotheres maculates	4,5,7
Pinnotheres ostreum	4,5,7
Polyonyx gibbesi	4,7
Portunus gibbesii	7
Portunus spinicarpus	7
Rhithropanopeus harrisii	2,3,4,5,7
Rhithropanopeus hermandii	7
Sesarma cinereum[R]	4
Sesarma reticulatum	4,5,7
Uca spp.	5,7
Uca minax	7
Upogebia affinis	4,7

Order Mysidacea (Mysids)

Bowmaniella dissimilis	7
Mysidopsis bigelowi	7
Neomysis americana	6,7

Order Cumacea

Leucon americanus	6

Order Stomatopoda

Squilla empusa (Mantis shrimp)	7

Order Amphipoda (Amphipods)

Caprella geometrica	7
Corophium lacustre	7
Cymadusa compta	3
Gammarus fasciatus	7
Gammarus mucronatus[+]	12
Monoculodes sp.*	7

Order Isopoda

Edotea sp.	7

Class Insecta

Order Diptera

Chaoborus punctipennis[*,L]	7
Ephydra sp.	7
Odonata sp.[*,R]	7
_Pentaneura monilis_*	7

Subclass Branchiura

Order Argulidea

Argulus sp. (Common fish lice)	7

Subclass Cirripedia

Order Thoracica

Balanus sp.[L] (Barnacle)	7

Phylum Chordata (Icthyplankton)

Class Osteichthyes (Bony fishes)[L]

Order Atheriniformes

Menidia beryllina (Inland silverside) 7
Menidia menidia (Atlantic silverside) 7
Membras martinica (Rough silverside) 7

Order Clupeiformes

Alosa mediocris (Hickory Shad) 7
Anchoa hepsetus[+] (Striped Anchovy) 7
Anchoa mitchelli (Bay Anchovy) 7

Order Gobiesociformes

*Gobiesox strumosus** (Skilletfish)

Order Perciformes

Cynoscion nebulosus (Weakfish) 7
Cynoscion regalis (Gray weakfish) 7
Ammodytes americanus[+,R] (American sandlance) 7
Bairdiella chrysoura (Silver perch) 7
Gobiosoma bosc (Naked goby) 7
*Gobiosoma ginsburgi** (Seaboard goby) 7
Leiostomus xanthurus (Spot) 7
Hypsoblennius hentzi (Feather blenny) 7
Menticirrhus saxatilis (Northern kingcroaker) 7
Micropogonias undulatus (Atlantic croaker) 7
Morone americana (White perch) 7
Morone saxatilis (Striped bass) 7
Peprilus paru (American harvestfish) 7
Perca flavescens (Yellow perch) 7
Pogonias cromis (Black Drum) 7

Order Pleuronectiformes

Pseudopleuronectes americanus (Winter flounder) 7
Scophthalmus aquosus (Widowpane) 7
Trinectes maculates (Hogchoaker) 7

Order Sygnathiformes

Hippocampus erectus (Lined seahorse) 7
Syngnathus fuscus (Northern pipefish) 7

Benthos of the York River

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ABSTRACT

Benthic organisms and their communities are key components of estuarine systems. We provide an overview of the biology and key ecological features of benthic communities of York River Estuary (YRE), which is the site of the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA). Major subtidal benthic habitats in YRE include soft mud and sand bottoms, with only limited distribution of submerged aquatic vegetation and oyster shell. Major taxonomic groups of macrofauna dominating muds and sands of YRE include annelids, molluscs and crustaceans; similar to those found in other temperate estuaries of the US Mid-Atlantic. Meiofaunal assemblages of YRE soft bottoms are dominated by nematodes and copepods. Species distribution patterns in YRE are strongly correlated with salinity and bottom type, while other factors such as eutrophication and hypoxia may be growing in importance. Much of the YRE benthos fails to meet the restoration goals set by the Chesapeake Bay Program. The poor condition of the benthos is expressed as low biomass and abundance and may be associated with degraded water quality, hypoxia and sediment disturbance processes. No comprehensive inventory of the benthic biota of the CBNERRS sites is available, which will make it difficult to assess future changes due to human impacts such as climate change or the introduction of exotic species. Given this paucity of data, a systemic cataloging of the benthic resources of the reserve sites and any potential invasive species is a much needed avenue of future research for CBNERRVA.

INTRODUCTION TO THE BENTHOS

The soft mud and sand habitats of the York River Estuary, as well as the interspersed patches of aquatic vegetation and oyster shell, support a wide variety of fauna and flora and are an important part of this productive coastal ecosystem. These bottom habitats and their resident organisms are called the benthos, derived from the Greek for "bottom of the sea." The animals comprising benthic communities, the zoobenthos[1], include almost every known phylum and exclusively encompass a number of them. For the purposes of this paper we have limited ourselves to a discussion of the benthic invertebrate residents and their communities of the York River Estuary. This is not to slight the countless numbers of bacteria, Archea, and protozoans that comprise the microbenthos, or the bottom-dwelling fish and crustaceans of the estuary, all of which are discussed in other papers in this issue.

Most benthic invertebrates are quite small and can be clearly distinguished only with the aid of magnification. They are classified into three major groups based on adult size. The smallest are the meiobenthos, which pass through a 500-µm mesh, but are retained on a 63-µm screen. Important taxa of meiobenthos include harpactacoid copepods, nematodes, ostracods and Foraminfera (see Higgins and Thiel, 1988). Macrobenthos are retained on a 500-µm mesh screen and are not readily identifiable without magnification. Annelid worms, bivalves, gastropods, crustaceans, tunicates, and insect larvae are commonly encountered macrobenthos in estuaries. The largest size-based category, the megabenthos, can be identified without magnification because individuals are typically multiple centimeters in size. This group includes animals such as crabs, bivalves, gastropods, sponges, colonial entoprocts and hydrozoans. Benthic organisms may progress through different categories as they grow. Many animals classified as macrobenthos start off as meiobenthic juveniles and are known as "temporary meiobenthos."

Beyond size, the mobility of an animal (motile versus sessile) and how it associates with the sediment or hard substrate (infaunal versus epibenthic) are other common ways benthic organisms are classified. Epibenthic animals live on or just above the substrate. They may be firmly attached (sessile), relatively sedentary, or fully motile. Animals such as barnacles, oysters, sponges, tunicates, entoprocts, gastropods, anthozoans, mud crabs, and certain species of amphipods are common representatives of the epibenthos. Animals that live within the substrate are called infauna and include most species of annelids and bivalves, larval insects, phoronids, as well as some species of amphipods and anthozoans.

MAJOR TAXONOMIC GROUPS OF BENTHIC FAUNA IN THE YORK ESTUARY

A comprehensive checklist of benthic animals in the York River Estuary and the greater Chesapeake Bay was published by Wass (1972). It provides frequency of occurrence and habitat preferences of those animals known at the time. There is no complete benthic invertebrate species list exclusively for the York River system; however, most of the benthic fauna found in the York River Estuary are listed in the regularly updated checklist available for the Chesapeake Bay Benthic

[1]The generic terms *benthos* and *benthic*, which are used to describe the bottom realm, have also been variously used to describe any and all of the organisms, from bacteria and microalgae to seagrasses and demersal predators, that are associated with benthic habitats. Use of the term *zoobenthos* provides more clarity, but in practice is rarely used by benthic ecologists working in the U.S.

Monitoring Program (Llansó, 2005). A partial checklist of benthic organisms in the York River Estuary developed from these and other sources is provided in the Appendix.

Poriferans

Sponges are colonial macro- to megabenthic-sized organisms. They filter feed by pumping water through inhalant and exhalent pores called ostia, trapping particles along the body wall, and ingesting them by phagocytosis (Brusca and Brusca, 1990). Most sponges in the York River Estuary are limited to the meso- to polyhaline reaches. Among the most conspicuous are the red beard (*Microciona prolifera*) and brown (*Haliclona* spp.) sponges, both of which grow attached to hard substrate (Figure 1). *M. prolifera* is frequently seen on pier pilings, while *Haliclona loosanoffi* is commonly found on the blades of submerged aquatic vegetation (SAV). The boring sponges, *Cliona* spp., erode galleries of passageways through calcareous shell of molluscs, which provides protection from predators. These types of sponges are considered nuisance species by commercial shellfish harvesters because the erosion of shell material is detrimental to living molluscs. All of the sponges found in the York River Estuary are capable of both sexual and asexual reproduction. Fragments of a sponge can grow an entire new sponge, given an appropriate substrate. Sexual reproduction in sponges is through broadcast spawning with most species thought to be hermaphroditic, which means that they switch between the production of male and female gametes during different parts of their lives (Brusca and Brusca, 1990).

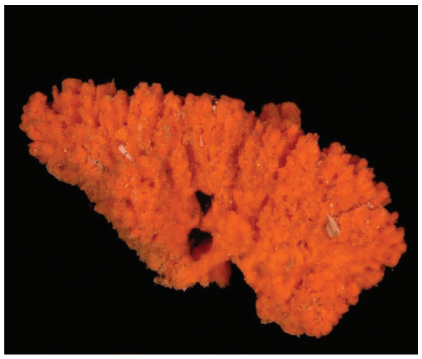

Figure 1. Unidentified red sponge. (Image courtesy of Southeastern Regional Taxonomic Center/South Carolina Department of Natural Resources)

Cnidarians

Representatives of all three classes of cnidarians (Hydrozoa, Anthozoa, and Scyphozoa) have been observed among the macrobenthic fauna of the York River Estuary. All cnidarians possess nematocysts, responsible for the familiar stinging sensation of jellyfish, which they use for both defensive and prey capturing purposes. Hydrozoans, the most conspicuous benthic cnidarians found in the York River Estuary, settle and grow on myriad substrates along the full salinity gradient. As passive filter feeders, hydroids rely on water currents to bring food particles to their feeding tentacles. Hydromedusae are found as solitary individuals and, more commonly, as colonies of many individuals or zooids that can create substantial colonies, extending several centimeters in to the water column. Colonial hydroids are abundant in the lower York River, where the large mounds they form on the bottom support a variety of other macrobenthic organisms (Figure 2) (Schaffner *et al.,* 2001). Hydrozoans have both sexual and asexual reproduction during different stages of their life cycle. Asexually, new hydroid zooids can be budded off an adult in an expansion of the colony, or as separate individuals in the non-colonial forms. Sexual reproduction in hydrozoans, much like the other types of cnidarians, is somewhat more complex. A free-swimming male or female medusa (jellyfish-like) stage is budded off of the benthic adult form, which in turn, releases gametes into the water column that when fertilized, form asexual, benthic individuals (Brusca and Brusca, 1990).

Figure 2. Colonial hydroids from the lower York River. (Image courtesy of Robert Diaz, VIMS)

Though less abundant and less diverse in the York River Estuary than hydrozoans, anthozoan (sea anemones) and scyphozoan (jelly fish) cnidarians are also found within the benthic communities. Like the hydrozoans, benthic anthozoans are passive filter feeders capable of both sexual and asexual reproduction. Anthozoans are non-simultaneous hermaphrodites that can bud off new individuals from the adult form, as well as produce male or female gametes. Anthozoans have lost the free-swimming medusa-stage of other cnidarians. The benthic adults directly release gametes to the water column, where they combine to form planular larvae that settle out of the water to from new benthic adults. Common anthozoans include epibenthic species (e.g., *Diadumene leucolena*) and infaunal species (*Ceriantheopsis americanus*, *Actiniaria* sp. or *Edwardsia elegans*) (Sagasti *et al.*, 2001; Llansó 2005). Scyphozoans are only ephemeral benthic organisms, but the benthic stage is an essential part of their reproductive lifestyle that occurs at various times of the year depending upon the species (see Steinberg and Condon this S.I.). This benthic stage is referred to as a scyphistoma and is an asexual from that buds off the familiar, pelagic medusae seen in the estuary.

Platyhelminthes

Flatworms are a small, relatively obscure component of the benthic community that can be found all along the estuarine salinity gradient. Free-living turbellarian flatworms can be macro- or meiobenthic in size and typically live within the upper few centimeters of sandy or muddy sediments, or on hard substrate (Martens and Schockaert, 1986). The most common estuarine turbellarians prey or scavenge upon the smaller benthos they encounter, such as meiobenthic harpacticoid copepods or nematodes, larger protozoans like Foraminifera, as well as macrobenthic oligochaetes and chironomids (Armitage and Young, 1990). Although living oysters are now uncommon in the York River Estuary, the oyster flatworm *Stylochus ellipticus* remains an important component of the ecosystem's hard substrate benthic community (Sagasti *et al.*, 2000). Parasitic flatworms (trematodes, monogenetic flukes, and cestodes) are also found within the estuary. They live on or within a variety of estuarine fauna, including fish, gastropods, or annelids. Most of the free-living species of turbellarians are hermaphroditic and are capable of both asexual (fission) and sexual (cross-fertilization) reproduction (Brusca and Brusca, 1990).

Nemerteans

Nemerteans are highly mobile, flat, non-segmented worms, commonly referred to as "ribbon worms." They are an ecologically important, though relatively poorly studied, taxonomic group within the benthic community of the York River. Nemerteans (Figure 3) can be quite large (often many centimeters in length) and move through the sediment by ciliary or peristaltic motion in larger species. Some of the largest nemerteans are burrowing predators (e.g., *Cerebratulus lacteus*), which move up from below to capture their prey with an eversible pharynx, which may be armed with a toxin-delivering stylet (Bourque *et al.*, 2002). Some species have quite advanced chemosensory detection capabilities and have been observed tracking potential prey items for some distance before striking (Brusca and Brusca, 1990). These chemosensory capabilities are also used to by nemerteans to track and locate mates for reproduction. Most nemerteans undergo sexual reproduction, with external or internal fertilization depending upon the species. Additionally, some species of the genus *Lineus*, a few species of which are observed in the York River Estuary (Wass, 1972), are also capable of asexual reproduction via fragmentation of the posterior end of the worm.

Figure 3. Unidentified nemertean. (Image courtesy Southeastern Regional Taxonomic Center/South Carolina Department of Natural Resources)

Nematodes

Meiobenthic nematodes are among the most numerically abundant benthic fauna in the York River Estuary (Alongi *et al.*, 1982; Metcalfe, 2005), though given their small size and somewhat obscure taxonomy, little species-specific research has been done on local nematode communities. These small, non-segmented round worms move through the interstitial spaces of sandy and muddy sediments. Nematodes encompass a wide variety of feeding styles, including deposit feeding, grazing, carnivory, interstitial filter-feeding, and parasitism, all of which, excluding the parasitic species, reproduce sexually with internal fertilization.

Entoprocts

Another example of a colonial filter-feeder, entoprocts (formally known as bryozoans) are epibenthos that will attach to almost any hard surface in the poly- and euhaline portions of the York River and other estuaries. Composed of numerous individual zooids, species commonly found in the York River Estuary such as *Pedicellina cernua* (Sagasti *et al.*, 2000), passively feed on passing plankton using ciliated tentacles (Figure 4). Entoprocts will undergo asexual budding within a given colony, but also periodically undergo sexual reproduction, broadcasting larvae into the water column to start new colonies (Brusca and Brusca, 1990). The zooids of entoprocts do not develop specialized functions like those of hydroids, but each individual is a protandric hermaphrodite, capable of both feeding and reproduction.

Figure 4. Unidentified branching, colonial entoproct. (Image courtesy of Southeastern Regional Taxonomic Center/ South Carolina Department of Natural Resources)

Annelids

This group of truly segmented worms includes the polychaetes, oligochaetes, and leeches. The annelids are a numerically abundant and ecologically important component of all benthic communities, including those of the York River Estuary. Within the estuary, annelids range in size from meiobenthic juveniles to megabenthic chaetopterid polychaetes and encompass all major feeding types and living positions.

Polychaetes are the most diverse group of annelids in the saline portions of the York River Estuary, with different species dominating in different salinity zones. *Polydora cornuta* and *Sabellaria vulgaris* are tube building, epibenthos commonly found on SAV or other hard substrates throughout the York River (Orth, 1973; Sagasti *et al.*, 2000). There are also highly mobile carnivores (e.g., *Eteone heteropoda* and *Glycinde solitaria*) with well-developed parapodia and cirri for mobility and sensory organs for tracking prey items (Figure 5). Many species of polychaetes are sessile infauna, living with their heads and feeding appendages at the sediment-water interface (e.g., *Loimia medusa*), or head down in the sediment with their tails at the surface (e.g., *Clymenella torquata*). Deposit feeders ingest bacteria, microalgae and organic matter associated with sediment particles and are common among the polychaetes. Filter-feeding is also common in the sessile

Figure 5. A common polychaete annelid *Neanthes succinea*. (Image courtesy of Southeastern Regional Taxonomic Center/South Carolina Department of Natural Resources)

polychaetes. Some species actively pump water into their tubes/burrows with their parapodia (e.g., *Spiochaetopterus costarum*), while others are capable of switching between passive filter-feeding and surface deposit-feeding with the anterior palps (e.g., *Streblospio benedicti*) (Fauchald and Jumars, 1979). Polychaetes primarily reproduce via sexual reproduction, wherein some species undergo internal fertilization and brood their larvae, while others are broadcast spawners with distinctive planktonic trochophore larvae.

Oligochaete annelids are also found throughout the York River Estuary, but are far less diverse than the polychaetes. They lack parapodia and typically have simple heads, without sensory palps or antennae, though some freshwater taxa have a proboscis for feeding (e.g., family Naidae). All of the oligochaetes found in the York River Estuary are motile, deposit feeders. Members of the genus *Tubificoides*, the naid *Paranais litoralis* and some species of the family Enchytraeidae are found in brackish and saline portions of the estuary. The tidal freshwater region contains a much more diverse assemblage of oligochaetes (e.g., *Limnodrilus hoffmeisteri*, *Aulodrilus templetoni*, *Dero digitata*). This pattern of higher diversity up-estuary reflects the radiation of oligochaetes into the estuary from freshwater systems (Stephenson, 1972). This contrasts with the pattern of diversity increasing with salinity in the estuary seen in many of the other estuarine invertebrates, which are descended from marine forms. All oligochaetes found in the estuary are simultaneously hermaphroditic and reproduce sexually, depositing cocoons into the mud or sand that contain a varied number of zygotes that grow and disperse after release. Some genera of oligochaetes, notably the naids, also reproduce asexually by budding offspring from their posterior regions (Stephenson, 1972). Asexual reproduction is a common means of reproduction during periods of favorable environmental conditions (food availability, temperature, etc.), but most species will switch to sexual reproduction when conditions become unfavorable (Stephenson, 1972).

The last sub-class of annelids found in the York River Estuary is the Hirudinae (leeches). Leeches are closely related to oligochaetes and are likewise simultaneous hermaphrodites with a reduced body structure devoid of parapodia or complex setae. Unlike oligochaetes, leeches reproduce strictly through sexual reproduction, producing cocoons they deposit into the environment. Most species of Hirudinae are exoparasites (e.g., *Myzobdella lugubris*, *Calliobdella vivida*) of other animals, though a few species (e.g., *Helobdella elongata*, *H. stagnalis*) are free-living predators of smaller invertebrates such as nematodes, copepods, or oligochaetes (Wass, 1972; Brusca and Brusca, 1990). Within the York River Estuary, these free-living species are primarily limited to the tidal freshwater and oligohaline waters (J. Williams, pers. comm.).

Echiurans

Echiurans are a phylum of non-segmented, worm-like animals that live in the high mesohaline to polyhaline parts of the estuary. Wass (1972) lists *Thallasema hartmani* as the only species commonly found in the estuary. Echiurans are sessile, surface deposit feeders. They build a tube in the sediment and feed with a long a proboscis that pulls sediment below the surface to the mouth. Echiurans have separate sexes and reproduce sexually in mass spawning events where gametes are released to the water column.

Arthropods

In terms of phylogeny and body form, arthropods are possibly the most diverse group of benthic organisms in the York River. These segmented animals have hard exoskeletons and jointed appendages, but range in form from barnacles to crabs. Arthropods of the estuarine benthic community reproduce via sexual reproduction, typically with external fertilization. Most arthropods are highly motile animals capable of swimming and walking, though barnacles are a notable, sessile exception.

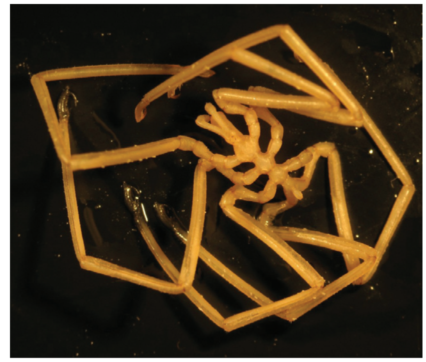

Figure 6. The pycnogonid *Pallenopsis schmitti*. (Image courtesy of D. Gillett)

Pycnogonids, or sea spiders (Class Chelicerata), are epifaunal arthropods (Figure 6) most commonly observed in fouling communities; among tunicates or sponges in the polyhaline and high mesohaline portions of the York River Estuary (e.g., *Anoplodactylus pygmaeus*, *Tanystylum orbiculare*, etc.) (Wass, 1972; Sagasti *et al.*, 2000). These mobile, spider-like arthropods are mostly carnivores, which feed upon other epifauna. There are some herbivores though, which feed on the algae growing in fouling communities (Brusca and Brusca, 1990).

Though they spend only a portion of their lives as benthic fauna, larval insects, predominantly of the Orders Diptera (flies and midges) and Trichoptera (caddis flies), are an important component of the tidal freshwater and oligohaline portions of the York River Estuary. Most families of insect larvae found living within the sediments span a range of feeding modes, from carnivore/scavengers (e.g., *Tanypus* sp.) to grazers (e.g., *Cryptochironomus* sp.). After a few weeks to months in the benthos, chironomid insect larvae metamorphose into adult dipterid and trichopterid flies and leave the system.

Crustaceans are the most taxonomically and trophically diverse group of benthic animals found in the estuary, as well the best known by the general public. Crustacean arthropods encompass the range of feeding types, including grazing, filter feeding, and deposit feeding. Macrobenthic crustaceans in the York River Estuary include sessile, filtering epifaunal organisms such as barnacles (*Balanus eburneus* and *B. improvisus*), motile, shrimp-like (peracarid) taxa like cumaceans (e.g., *Leucon americanus* or *Cyclaspis varians*) and mysids (e.g., *Neomysis americana*) that live on the sediment surface, mobile burrowing isopods (e.g., *Cyathura polita* or *Edotea triloba*), and amphipods (e.g., *Leptocheirus plumulosus*, *Protohaustorius deichmannae*, or *Caprella penantis*) (Figure 7). Decapod crustaceans include one the most famous benthic organisms of the estuary, the blue crab (*Callinectes sapidus*), as well as some smaller less well-known members, such as xanthid mud crabs (e.g., *Rhithropanopeus harrisii*). Many of the small crabs that populate the estuary are relatively cryptic, living among shells and other structured benthic habitats such as sponges. Fiddler crabs (*Uca* spp.), which live in the intertidal salt marshes that line the banks of the estuary, are a common sight to most people. The most abundant crustaceans in the York River Estuary, meiobenthic harpactacoid copepods (e.g., *Euterpina acutifrons* or *Canuella canadensis*), reside near the sediment-water interface among sediment grains of the estuarine bottom and are important grazers of bacteria and micro-algae.

Figure 7. *Leptocheirus plumulosus*, a common amphipod in the York River Estuary. (Image courtesy of D. Gillett)

Molluscs

Benthic molluscs in the York River Estuary include the conspicuous and familiar clams and snails that can live multiple years and in some cases, e.g., oysters and mussels, are capable of creating complex, hard bottom habitats that provide living space and refugia for other benthic organisms. The most common molluscs of the York River Estuary can be divided into two groups based on the shape and number of shells they have: bivalves, with two relative concave shells, e.g., clams (*Macoma balthica* or *Mya arenaria*), oysters (*Crassostrea virginica*), and mussels (*Geukensia dermissa*); or gastropod snails, which have a single, typically spiraled shell that includes whelks (*Busycon canaliculatum*) and mud snails (*Littorina littorea* or *Hydrobia* sp.).

Bivalves are found along the length of the York River Estuary in all of the salinity zones and typically comprise a significant amount of the total biomass of the infaunal benthic communities (Diaz and Schaffner, 1990; Schaffner *et al.,* 2001). All of the bivalves found in the York River Estuary reproduce sexually, broadcasting their gametes into the water column, creating planktonic larvae. Most are filter feeders (Figure 8), though one of the dominant genera in the meso- and polyhaline portions of the estuary, *Macoma*, is a functional deposit-feeder that can switch from filter feeding to deposit feeding depending upon the water currents and food availability (Pohlo, 1982). Large reefs of the eastern oyster *C. virginica* were once dominant benthic features of the York River, but overfishing, habitat destruction and disease have lead to their demise (Figure 9.) (Hargis and Haven, 1999) and the ecological importance of the oyster has been drastically reduced (Pomeroy *et al.*, 2006; Coen *et al.*, 2007).

Figure 8. *Macoma balthica*, one of the most common infaunal bivalve molluscs in the York River Estuary. Note the incurrent and excurrent siphons protruding from the top of the shell. (Image courtesy of Heidi Mahon, Old Dominion University)

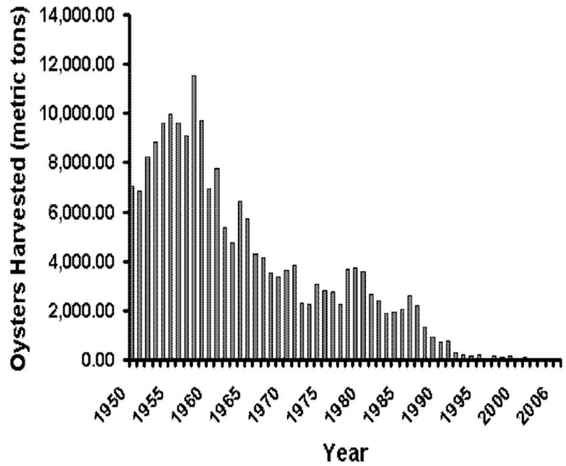

Figure 9. Commercial landings of the Eastern Oyster *Crassostrea virginica* in Virginia from 1950 – 2006. Data from the National Marine Fisheries Service (NMFS)

Gastropods are among the most voracious predators in the benthos. Large whelks, such as the channeled whelk *B. canaliculatum* and the non-native veined rapa whelk *Rapana venosa,* are a considerable problem for commercial bivalve aquaculture operations (J. Harding, pers. comm.). Other gastropods feed on benthic microalgae in the shallow subtidal and intertidal flats of the estuary (e.g., *Hydrobia* sp. or *Narssarius obsoletus*) or on the epiphytic microbes found on the stalks of intertidal marsh grass (e.g. the marsh periwinkle *Littorina littorea*). Gastropods reproduce sexually, undergoing internal fertilization, with the females attaching their egg cases the sediment surface or some hard structure in the environment (e.g., shell material or SAV blades,).

STUDIES OF BENTHIC FAUNA IN THE YORK RIVER

Because of the economic importance of the oyster fishery and the feared decline in the resource, significant effort was put into quantifying the abundance and spatial extent of eastern oyster (*C. virginica*) reefs in the York River by the state of Virginia from at least the mid 1800's, (Wheatley, 1959; Hargis and Haven, 1999). These works, most notably the Baylor survey of 1900, represented the first surveys of benthic biota within the York River Estuary; even in light of their focus on one organism and the delineation of fishing rights. The quantitative study of the complete benthic communities of the York River Estuary began in earnest in the mid-1960's, led by scientists of the Virginia Institute of Marine Science (VIMS). Notable early studies include those of Wass (1965), Haven *et al.* (1981) [*note: Haven* et al. *collected data in 1965-1966, but did not published until 1981*], and Boesch (1971). Initial studies focused on describing benthic community composition of major York River habitats. Based on a review of the early literature for Chesapeake Bay and the major sub-estuaries, distribution and abundance patterns of dominant macrobenthic organisms of soft sediment habitats were summarized by Diaz and Schaffner (1990) (Table 1). Marsh (1970) and Orth (1973) identified the epifaunal and infaunal communities of sea grass beds in the lower York River Estuary.

Table 1. Physical and benthic community characteristics of the major benthic habitats of the York River estuary. Modified from DIAZ and SCHAFFNER, 1990.

Salinity/Habitat Type	Reserve Site(s)	Physical Characteristics	Macrobenthic Community Characteristics	Macrofauna Density / Taxa of Note	Macrofauna Biomass / Taxa of Note
Tidal Freshwater					
Shoals	Sweet Hall Marsh	Shallow depths Mud to sand sediments Wave- and tide-dominated High turbidity Low to moderate light penetration	Stenohaline freshwater fauna Deposit and suspension feeders Infaunal predators Many ephemeral fauna Moderate to low diversity	Low to moderate *Limnodrilus* spp., *Illydrilus templetoni*, *Stephensonia trivandrana*, *Coelotanypus* spp.	Oligochaetes and bivalves high Others low *Limnodrilus* spp., *Illydrilus templetoni*, and *Rangia cuneata*
Channels		Intermediate depths Mud to sand sediments Fluid mud possible Tide dominated High turbidity No light penetration	Stenohaline freshwater fauna Deposit and Suspension feeders Moderate to low diversity	Low, especially in areas of fluid mud	Bivalves high Others low
Oligohaline					
Shoals	Taskinas Creek	Shallow depths Mud and sand sediments Wave- and tide-dominated Region of estuarine turbidity maximum (ETM) High deposition Low to moderate light penetration	Euryhaline estuarine fauna Deposit and suspension feeders Some ephemeral fauna Low diversity	Low to high *Tubificoides heterochaetus*, *Tubificoides brownae*, *Leptocheirus plumulosus*	Bivalves high Others low *Marenzelleria viridis*, *Macoma balthica*, *Cyathura polita*
Channels		Moderate depths Mud sediments Fluid mud possible Tide-dominated Region of ETM High deposition No light penetration Occasional low oxygen	Euryhaline estuarine fauna Deposit and suspension feeders Low diversity	Low to high *Marenzelleria viridis*, *Leucon americanus*	Bivalves high Others low *Macoma balthica*
Mesohaline					
Shoals	Cattlet Islands Timberneck Creek	Shallow depths Sand and mud sediments Wave- and tide-dominated Low to moderate turbidity Moderate light penetration Occasional low oxygen	Euryhaline estuarine fauna All feeding types Moderate diversity	Moderate to high *Streblospio benedicti*, *Mediomastus ambiseta*, *Leptocheirus plumulosus*	Bivalves high Others moderate *Macoma balthica*, *Loimia medusa*, *Clymenella torquata*, *Paraprionospio pinnata*
Channels		Intermediate to deep depths Mud sediments Fluid mud possible Tide-dominated High turbidity, related to secondary ETM No light penetration Seasonal low oxygen	Euryhaline estuarine fauna All feeding types Moderate diversity*	Moderate to high* *Streblospio benedicti*, *Mediomastus ambiseta*	Bivalves high* Others moderate* *Macoma balthica*, *Paraprionospio pinnata*
Polyhaline					
Shoals	Goodwin Islands	Shallow depths Sand sediments Wave- and tide dominated High light penetration	Stenohaline estuarine/marine fauna All feeding types Moderate diversity	Low to moderate *Streblospio benedicti*, *Spiochaetopterus oculatus*	Low to moderate *Mercenaria mercenaria*, *Mya arenaria*
Channels		Moderate to deep depths Mud to sand sediments Tide-dominated Moderate turbidity No light penetration Seasonal low oxygen	Stenohaline estuarine/marine fauna All feeding types Moderate to high diversity*	Moderate* *Acteocina canaliculata*, *Heteromastus filiformis*	Low to high *Mercenaria mercenaria*, *Chaetopterus variopedatus*

* Except when low oxygen conditions prevail.

Studies to assess the potential impact of anthropogenic disturbances in the York River Estuary were conducted by scientists at VIMS beginning in the 1970's (e.g., Jordan *et al.*, 1975; Boesch and Rosenberg, 1981; Alongi *et al.*, 1982). Monitoring of macrobenthic communities in the York River began in the 1980's as part of a larger monitoring program coordinated by the Chesapeake Bay Program (CBP), which is funded by USEPA (United States Environmental Protection Agency), NOAA (National Oceanographic and Atmospheric Association) and the states in the Chesapeake Bay watershed. Samples for infaunal macrobenthos (non-colonial forms only) of soft sediment habitats have been collected at a series of fixed and random stations throughout the Chesapeake Bay, including four fixed stations in the York and Pamunkey Rivers. The four fixed stations, all located in the main channel of the estuary, were sampled quarterly between 1984 and 1994 and subsequently reduced to the present schedule of once a year. Beginning in 1996 the sampling design was changed and 25 samples are now collected in the York-Pamunkey estuarine system each summer (July 15 – September 30) based on a probabilistic sampling design that stratifies the estuary by salinity regime and water depth (Llansó *et al.*, 2006). These monitoring studies provide a wealth of information about the infauna of the York River Estuary, much of which is now available online www.chesapeakebay.net/baybio.htm. Some of the major studies describing the monitoring program and its findings are presented in Weisberg *et al.* (1997), Dauer *et al.* (2000), Alden *et al.* (2002) and Llansó *et al.* (2003).

DISTRIBUTION OF MACROBENTHIC COMMUNITIES ALONG THE ESTUARINE GRADIENT

Benthic studies of the York, James and mainstem Chesapeake Bay regions have clearly demonstrated the strong relationship between benthic community structure and salinity regime (see review by Diaz and Schaffner, 1990). For ease of comparison, the salinity regime of estuarine waters is typically referred to within the Venice salinity classification system (International Association of Limnology, 1958). Salinity in the York is relatively stable, with typical daily changes of less than 5 psu (practical salinity units) at a given location (Boesch, 1977; Schaffner *et al.*, 2001). Freshwater flow is from the Pamunkey and Mattaponi Rivers, but is relatively low overall, with the York receiving only about 6% of the freshwater entering the Chesapeake Bay from the watershed each year.

Salinity affects osmotic balance and ion regulation of most aquatic organisms. Given the variability of salinity in most estuaries, resident invertebrates must be relatively tolerant. Although some benthic organisms have a wider range of salinity tolerance than others, few species of benthic invertebrates are capable of maintaining physiological function over the full salinity range observed in an estuary, even when local populations become acclimated. Rapid changes in salinity are especially problematic and pulses of fresher water, due to major spring freshets and hurricanes, can act as disturbances to the benthic community (e.g., Boesch and Rosenberg, 1981; Dauer *et al.*, 2000; Holland *et al.*, 2004).

A classic pattern observed for macrobenthic communities of estuarine and other brackish water environments is the relationship between salinity and species diversity (Remane and Schlieper, 1971; Gainey and Greenberg, 1977; Deaton and Greenberg, 1986). In large brackish water systems such as the Baltic, or in estuaries that are relatively homeohaline, diversity has been shown to decrease when moving from higher salinity waters to a minimum in at 2 - 7 PSU and then increases again moving into freshwater (Attrill, 2002). The pattern of declining diversity with declining salinity is observed in the York River Estuary (Boesch, 1971; Boesch *et al.*, 1976; Schaffner *et al.*, 2001), but the pattern in oligohaline to tidal freshwater is not well defined due to limited sampling. Diaz (1989, 1994) found that species diversity did not increase substantially in the tidal freshwater region of the nearby James River estuary and attributed it to the highly variable and physically stressful nature of the region.

Distribution and abundance of benthic species in soft sediment habitats of the York River Estuary is further correlated with bottom type, hydrodynamics, oxygen regime, and other variables that may covary with salinity along the estuarine gradient (see review by Schaffner *et al.*, 2001). Bottom types in the estuary range from cohesive silts and clays to well-sorted sands (Figure 10) (Schaffner *et al.*, 2001; Schaffner unpublished). In the broad lower York, wave energy is a major factor determining sediment distribution patterns. Fine sediment is winnowed away and the bottom is floored mostly by sand and shell in shallow areas (< 10 m depth), while muds tend to accumulate in the channel. In the middle to upper estuary, upstream of Gloucester Point, tidal energy and estuarine circulation become the more important determinants of sediment distribution. Estuarine circulation processes lead to trapping of fine particles, particularly during periods of high freshwater input. Relatively strong tidal scouring of the channel bottom, and strong wave energy on the shoals during some seasons, but not others, results in significant resuspension of sediment and physical disturbance of the bottom (Dellapenna *et al.*, 1998, 2003; Schaffner *et al.*, 2001), which influences the structure and productivity of subtidal benthic communities in this region of the estuary (Schaffner *et al.*, 2001; Hinchey, 2002.).

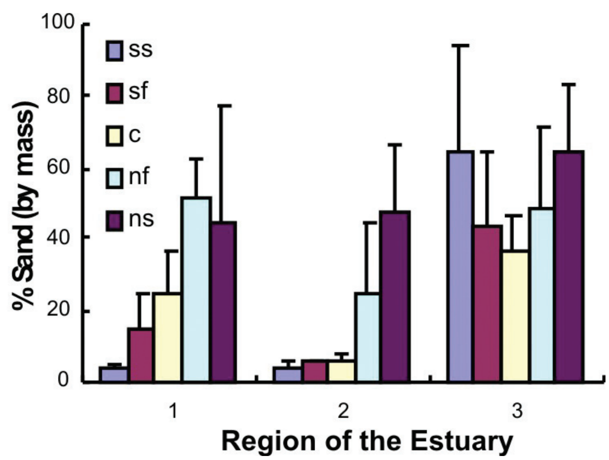

Figure 10. Mean grain size of sediment distributed throughout the York River + 1 standard error. Regions of the Estuary: 1= upper York River, 2 = mid-York River, 3 = lower York River. ss = southwest shoal, sf = southwest flank, c = channel, nf = northeast flank, and ns = northeast shoal.

Benthic fauna exhibit sediment preferences that are reflected in their living positions and feeding mechanisms. As noted above, meiobenthic fauna such as harpactacoid copepods, nematodes, and ostracods live within the spaces between individual sediment grains (the interstitial spaces), ingesting individual particles or filtering the porewater. Sediment with high clay content may become compacted and rich in sulfides, which limits habitat for meiofauna (Higgins and Thiel, 1988). For larger benthic organisms, feeding type may determine the suitability of a given sediment type. Highly mobile, non-selective deposit feeders (e.g. capitellid polychaetes and oligochaetes) tend to be more abundant in depositional areas where organic rich sediment particles accumulate and higher sediment water content makes burrowing easier (Lopez and Levinton, 1987; Rice and Rhoades, 1989). Sandier sediment provides favorable habitat for filter feeders, which have passive collection mechanisms (e.g., phoronids, bryozoans, or hydroids) or limited ability to sort captured particles (e.g., venerid bivalves or chaetopterid polychaetes). In turbid, soft sediment areas of the estuary, smaller silt or clay particles may clog these delicate filtering structures (Lopez and Levinton, 1987; Rice and Rhoades, 1989). Many benthic taxa of estuaries live equally well in the middle ground of muddy-sands and sandy-muds, particularly those that are capable of switching between deposit feeding and filter feeding as water flow conditions change (e.g., tellinid bivalves or spionid polychaetes) (Taghon *et al.*, 1980; Pohlo, 1982; Dauer, 1983**).** In the deeper waters of the York, bivalves, including both filter and surface deposit feeders, are especially abundant downstream of the estuarine turbidity maximum, which is an area high phytoplankton production (Sin *et al.*, 1999; Schaffner *et al.,* 2001).

Hypoxia and anoxia are common during summer months in the deep channel of the lower York River Estuary, whereas the shallow shoals almost always remain well mixed and oxygenated. Low oxygen events, which typically last a week or less, occur primarily during periods of summer neap tides, when stratification of the water column tends to be strong and respiration is high (Haas, 1977; Diaz *et al.*, 1992). Oxygen is replenished to bottom waters during periods of spring tide due to physical mixing. Episodes of hypoxia or anoxia result in mortality of sensitive taxa (e.g., forams, most species of crustaceans, and some families of polychaetes) and create communities dominated by stress-resistant taxa that tolerate the events, or opportunistic taxa that are able to quickly able recolonize disturbed areas (Diaz and Rosenberg, 1995; Sagasti *et al.*, 2000; Sagasti *et al.*, 2001; Metcalfe, 2005).

Physical structure within estuarine habitats also influences the composition and abundance of macrobenthic communities. Oyster reefs were once a predominant feature of estuaries like the York River (Hargis and Haven, 1999). Reefs provide important ecosystem services, including substrate for sessile forms, such as sponges, entoprocts, and barnacles, shelter for motile species, such xanthid crabs, and filtration by the oyster reef community contributes to improving water clarity, which may benefit nearby sea grass meadows (Coen *et al.*, 1999; Harwell, 2004; Cerco and Noel, 2007). Due to over-harvest, disease, and declining water quality there are no longer large oyster reefs in the York River estuary (Hargis and Haven, 1999), though shell clusters may still provide a habitat for other macrobenthos (Figure 11) (Schaffner, unpublished). The proliferation of other structures in the estuary (e.g., piers, bridges, hardened shore lines, stake arrays that support fishing nets, and even ghost crab pots) have created hard substrate habitat that is used by these epifaunal macroinvertebrates, though possibly not to the same degree as oyster reefs did in the past (Pomeroy *et al.*, 2006).

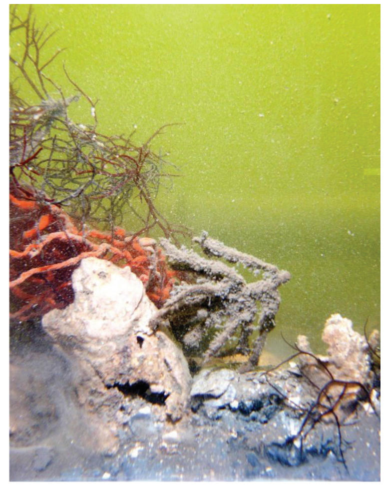

Figure 11. An epifaunal community of sponges, hydroids, entoprocts, and other fauna attached to shell rubble at Catlett Islands in the York River. (Image courtesy of Robert Diaz, VIMS)

Submerged aquatic vegetation (SAV) also increases habitat complexity, and its presence results in the formation of unique assemblages of macrobenthos in shallow estuarine waters. Orth (1973) characterized the macrobenthic infauna associated with *Zostera marina* beds in the high-mesohaline and polyhaline portions of the York River. He found a community very similar in composition to that which has been found in unvegetated habitats within the same salinity zone (e.g., Boesch, 1971; Bender, 1972; Jordan *et al.,* 1975). Wass (1972) provided some cataloging of the fauna attached to SAV (e.g., sponges, tunicates, etc.) and Orth and Van Montfrans (1984) and Duffy and Harvilicz (2001) have discussed the composition of the motile epifaunal grazing communities of SAV beds in the higher salinity, including amphipods, isopods and snails. Although none of the macroinvertebrates found in beds of SAV are unique to those environments, some of them may be more abundant in SAV than they are in other benthic habitats. Unfortunately, much like oyster reefs, the occurrence of SAV meadows within the York River Estuary has precipitously declined from historical levels in recent decades, due in large part to anthropogenic alterations to the estuary (Moore *et al.*, 1996; Orth and Moore, 1983; Moore, this S.I.).

Imposed upon the large-scale changes in community structure along the length of the York River Estuary, there are also changes in community structure with depth (Diaz and Schaffner, 1990; Table 1). The York River Estuary consists of a relatively deep channel (9 – 25 m) flanked by shallow (2-3 m), sometimes quite broad shoals and tidal creeks (Schaffner *et al.*, 2001). In the shallow areas, light may penetrate to the sediment surface where it provides energy for the growth of microphytobenthos, an energy-rich food source for benthic fauna (MacIntyre *et al.*, 1996; Cahoon, 1999). Phytoplankton production can also have a greater influence on the macrobenthic community in the shallow portions of the estuary, where filter feeding animals have access to the entire overlying water column and living phytoplankton, as opposed to those animals in deeper parts of the estuary that are isolated from the photic zone by stratification of the water column (Gerritsen *et al.*, 1994). Relatively labile detrital materials may also be available due to the proximity to marshes and SAV beds. These additional food sources allow for higher productivity of the benthic community in areas where recruitment and growth are not limited by other factors (Beukema and Cadee, 1997).

While food availability may enhance the potential for high secondary productivity in shallow water areas, other factors may be limiting. Physical disturbance due to waves, strong predation, temperature extremes and other factors alter benthic community structure and may limit productivity in shallow water areas despite high food availability (Emerson, 1989; Beukema and Cadee, 1997; Harley *et al.*, 2006). Predation on meio- and macrobenthos is often intense in shallow water areas due to the juxtaposition of highly productive shallow water benthic habitats with marsh and SAV beds that provide smaller predators of benthic infauna, such as juvenile fish, crabs, and large infauna, refuge from larger predators (Kneib, 1997; Seitz *et al.*, 2005; Seitz *et al.*, 2006). Benthic invertebrates living in shallow subtidal and intertidal zones are also subject to predation by birds (Kiviat, 1989).

THE IMPORTANCE OF BENTHIC FAUNA

Despite their relatively small size and cryptic lifestyle, macro and meiobenthos are important components of the estuarine ecosystem, serving as critical links between the variety of organic matter sources in estuaries (e.g., phytoplankton, benthic micro- and macroalgae, detritus) and the economically, ecological, and recreationally important finfish and crustaceans that live there (Cicchetti, 1998). Baird & Ulanowicz (1989) estimated that approximately 50% of the fish production in Chesapeake Bay is directly linked to a benthic food web. Diaz and Schaffner (1990) estimated that 194,000 metric tons of carbon is produced by benthic macrofauna in Chesapeake Bay each year (70% of which occurs in high mesohaline and polyhaline habitats) and supports a fisheries yield of 27,500 metric tons of carbon. Commercial fisheries of benthic feeding and demersal nekton (e.g., spot, croaker, blue crabs) in the Virginia portion of Chesapeake Bay yielded an annual average of 39.8 million dollars of revenue between 1998 and 2002 (NMFS, Fisheries Statistics and Economics Division, 2004). Direct harvest of benthic species, especially the oysters and other bivalves, were historically important fisheries in the York River Estuary (Wheatley, 1959; Bender, 1987; Hargis and Haven, 1999), though now they constitute less than one million dollars in landings Bay-wide (NMFS, Fisheries Statistics and Economics Division, 2004) (Figure 9). Commercial aquaculture of bivalve molluscs, particularly the hard clam *Mercenaria mercenaria*, has become an important economic force in the Chesapeake Bay as a whole (Camara, 2001; VA Sea Grant, 2007), though there are no large-scale operations within the York River Estuary. Benthic communities also provide a variety of ecosystem services that affect water and sediment quality in the estuaries. In relatively shallow areas, filter feeders may effectively remove particles from the water column, which leads to deposition of organic matter from the overlying water at rates greater than natural sinking and physical mixing would allow. This can result in enhanced water clarity, which may increase the success of SAV (Newell and Koch, 2004). SAV may also enhance particle deposition due to a baffling effect. Biodeposition by filter feeders also serves to shunt water column production to the sediment bed where transport, transformation and fates are then governed by benthic rather than pelagic processes (Cohen *et al.*, 1984; Gerritsen *et al.,* 1994; Neubauer, 2000). Some of this organic matter will fuel the production of benthic invertebrates and their predators. Organic matter that is not assimilated by macro and meiobenthic organisms may be buried, but more likely, it will be processed by microbes. The released nutrients and breakdown products may be retained in sediment pore waters or fluxed across the sediment-water interface.

Microbial processes generally control the rates of most important biogeochemical processes in the sediment, while meio- and macrobenthos control the mixing of constituents such as oxygen and organic matter that settles or is deposited to the estuary floor. Bioturbation and biogenic structuring of the bottom by benthic organisms has been show to have major effects on carbon, nitrogen, phosphorus, and contaminant cycling and fate (Diaz and Schaffner, 1990). The degradation of organic matter and some contaminants is generally enhanced in the presence of infaunal organisms, due to stimulation of microbial processes, which leads to enhanced rates of mineralization (Aller and Aller, 1998; Kristensen, 2000). Bioturbation and sediment ventilation by larger benthic organisms tend to enhance the diffusivity of dissolved constituents such as ammonium into the water column (Rice and Rhoades, 1989; Michaud *et al.*, 2005; Michaud *et al.,* 2006). Simultaneously, reduction/oxidation sensitive processes, such as nitrification-denitrification, may be enhanced in the presence of macrofauna whose tubes and burrows increase the surface area of the sediment-water interface and the depth of oxygen penetration into the sediment. The enhanced coupling of nitrification-denitrification in the presence of benthic macrofauna can lead to the production of nitrogen gas, which escapes to the atmosphere, thereby reducing the nitrogen load in the estuary (Mayer *et al.*, 1995).

THE BENTHIC FAUNA OF CBNEERVA

As noted above, the shallow waters of the York River Estuary historically contained a variety of different habitat types, with extensive SAV beds and oyster reefs interspersed with open areas of mud and sand flats. At present, the estuary is floored mostly by unvegetated mud or sand sediments with very limited, narrow bands of SAV beds in some areas. As such, soft sediment communities have been the most well-studied, both temporally and spatially (see Studies of the Benthic Fauna of the York River, above). These habitats provide the best characterization the benthic communities throughout the whole estuary and within each of the salinity zones where the different parts of the CBNERRS VA reserve are located (Table 1). Within these generalized benthic communities though, there is almost always a considerable amount of patchiness in space for most species and in time for others, particularly those with strongly seasonal recruitment (e.g., bivalves and polychaetes) (Kravitz, 1983; Zobrist, 1988; Hinchey, 2002).

INVASIVE/NON-NATIVE ORGANISMS IN THE YORK RIVER ESTUARY

The presence or distribution of invasive benthic fauna in the York River Estuary remains poorly studies. Invasive taxa have been found in other parts of Chesapeake Bay. The Asian clams *Corbicula manilensis* and *C. fluminea*, which are thought to have invaded other tributaries of the Chesapeake Bay around 1968 (Wass, 1972; Diaz, 1974; Phelps, 1994), were not historically observed in the York River Estuary (Boesch, 1971), but have recently been collected in the Chesapeake Bay Benthic Monitoring Program (Chesapeake Bay Program, 2009). There are regular observations of the veined rapa whelk *Ra-*

pana venosa (Figure 12), an invasive gastropod accidentally introduced to the high mesohaline/polyhaline York River in the mid-1990's. This species may severely impacts bivalve fisheries via predation (Harding and Mann, 2005). Additionally, the history of colonial activity in the York River increases the likelihood that some of the species considered to be natives were introduced before scientific surveys began.

Figure 12. The invasive gastropod *Rapana venosa* collected from the York River. (Image courtesy of Juliana Harding, VIMS)

There are also examples of deliberate introduction of non-native species, most notably the non-native oysters *Crasostrea gigas* and *C. ariakensis*. These species that have been introduced to the mesohaline and polyhaline portions of the York River in the interest of supplementing/replacing the oyster fishing industry, which traditionally was based upon the native *C. virginica*. Introduced non-native species may directly compete with native fauna for resources and serve as means for unintentional introductions of parasites and other cryptic fauna associated the non-natives (Dobson and May, 1986; Carlton, 1992). In recognition of these potential problems, only sterilized, non-reproductive *C. ariakensis* have been introduced to date into the York River in experimental deployments by VIMS and the Virginia Seafood Council. In the end, the true abundance and distribution of invasive benthic taxa in estuaries like the York River and its tributaries will remain difficult to definitively quantify due to the size of the estuary, the cryptic nature of native and non-native benthic organisms, and the ephemeral and stochastic nature of most invasions (Carlton, 1996).

HUMAN PERTURBATIONS OF BENTHIC FAUNA

The annual benthic monitoring program of the Chesapeake Bay Program assesses the quality and degree of benthic habitat degradation in the Chesapeake Bay and its tributaries using the macrobenthos and the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) (Weisberg *et al.*, 1997). Based upon randomly selected sites in 2005 (the most currently available data) and the B-IBI assessment approach, 73% of the area of the York River Estuary failed to meet the restoration goals set by the Chesapeake Bay Program, due in large part to low macrobenthic abundance and biomass (Llansó *et al.*, 2006). The distribution of habitat quality is not uniform along the length of the estuary (Figure 13). Most of the degraded sites fall within the polyhaline and mesohaline portions of the York River, areas known to be affected by low dissolved oxygen (Llansó *et al.*, 2006). In contrast, benthic communities of sites sampled in the oligohaline and tidal freshwater parts of the York River were assessed as non-degraded (Llansó *et al.*, 2006).

The hypoxic and anoxic waters observed in the York River Estuary are the end product of a complex process created by excessive nutrient inputs into Chesapeake Bay and human development and alteration of the Bay's watershed (Reay and Moore, this S.I.; Dauer *et al.*, 2000). Hypoxic episodes in the York River are periodic in nature, lasting from hours to over a week at a time during late summer (Haas, 1977; Diaz *et al.*, 1992). Direct mortality of benthic fauna via suffocation will occur during persistent, multi-day episodes of hypoxia/anoxia, though the length of time an organism can survive without oxygen will vary from species to species (Holland *et al.*, 1977; Diaz and Rosenberg, 1995; Sagasti *et al.*, 2001; Sagasti *et al.*, 2003). Relatively low levels of dissolved oxygen are always present in the sediment of estuaries given the abundance of organic matter and the subsequent respiration of heterotrophic bacteria. These processes result in the accumulation of reduced compounds in the sediment pore waters (e.g., sulphides, ammonia) that are toxic to benthic organisms (Theede *et al.*, 1973; Pearson and Rosenberg, 1978; Shin *et al.*, 2006). Water column hypoxia exacerbates the sediment system, increasing the concentrations of reduced chemicals and preventing a source of oxygen to oxidize and remove these

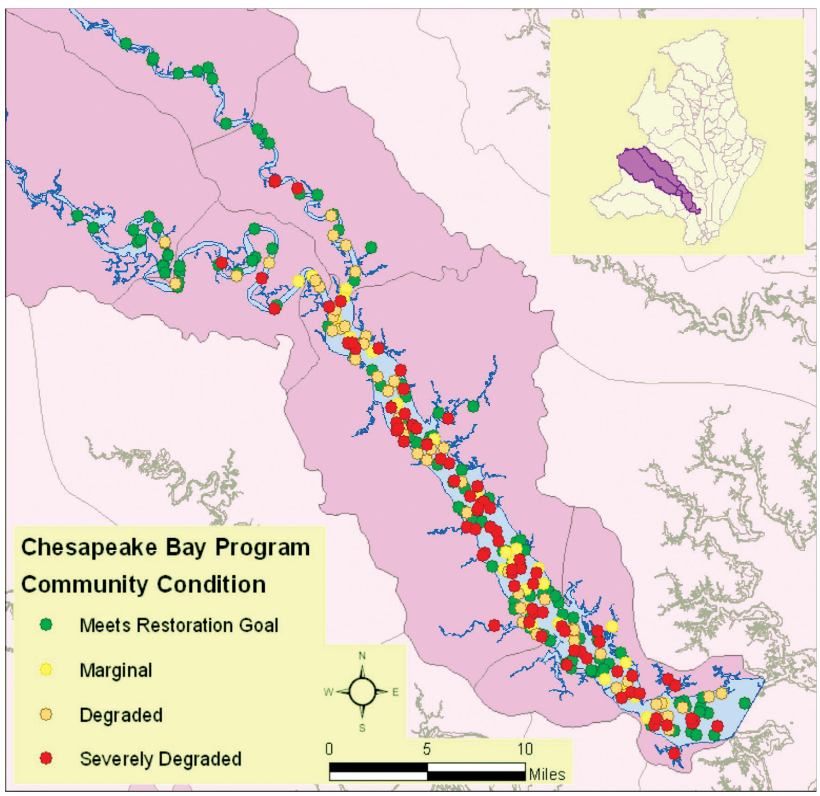

Figure 13. Benthic habitat condition at randomly selected sites within the York River Estuary from 1996 – 2006. Benthic habitat condition was assessed using the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) and graded using the Chesapeake Bay Program's restoration guidelines: B-IBI ≥ 3.0 = Meets Restoration Guidelines; 2.7 – 2.9 = Marginal; 2.1 - 2.6 = Degraded; and ≤ 2.0 = Severely Degraded, as noted in the legend. (Data from CBP database and figure created by David Parrish, CBNERRSVA)

toxic chemicals (Gaston *et al*., 1985; Diaz and Rosenberg, 1995; Levin, 2003).

By most accounts, the York River Estuary is not systemically affected by chemically contaminated sediments, unlike more developed parts of Chesapeake Bay (e.g., Elizabeth River, Baltimore Harbor, etc.) (Llansó *et al*., 2006). That said, there are inevitably instances of local contamination in areas surrounding the various marinas along the length of the estuary, the U.S. Navy installations in the mesohaline estuary, and the coal-fired power plant and petroleum refinery in the polyhaline parts of the estuary. Fuels spills that contain toxic polycyclic aromatic hydrocarbons (PAHs) occur, older military landfills leach a variety of toxic compounds (e.g., chlorinated compounds or asbestos), and anti-fouling compounds with heavy metals leach from ships into the water column, all of which can bind to sediments and negatively impact the benthic fauna of the estuary (e.g., Jordon *et al*., 1975; Lynch and Bull, 2007; USEPA 2007).

AREAS OF FUTURE RESEARCH

One of the strategic goals of the National Estuarine Research Reserve System program is to characterize and monitor the biological and community conditions of the reserves, to establish reference conditions, and to quantify change (NERRS 2005). Thus, an understanding of the composition of the benthic community should be of primary concern to the CB NERRS VA program. A comprehensive baseline inventory of the benthic fauna at each of the reserve sites, from the sand and mud flats of the Goodwin Islands to the tidal creeks of Sweet Hall Marsh. Recent research projects conducted at different parts of the reserve system will provide some insight into the macro- and meiobenthic community structure (Gillett, unpublished; Schaffner and Gillett, unpublished) and serve as a good starting point, but these studies were not designed to catalog the entire benthic community. Without knowledge of the fauna of different parts of the York River Estuary, it will be impossible to track future invasions, or to assess the role of anthropogenic factors such as development or climate change, in the alteration of benthic community structure and function. Benthic community data is most acutely lacking in the tidal freshwater and oligohaline portions of the York River Estuary. The reserve would benefit significantly by beginning a benthic community investigation at the Sweet Hall Marsh and Taskinas Creek portions of the reserve system before the further development of the watershed begins to degrade the habitat quality in those regions.

In addition to establishing the resident fauna for each portion of the reserve, habitat mapping and inter-habitat comparisons should be completed. Comparisons of the communities in the unvegetated sediment, natural and artificial hard bottom, and SAV meadows will allow the reserve managers to better assess the ecological complexity and ecosystem services rendered within the different parts of the reserve and along the salinity gradient of the York River Estuary. This is key information needed for developing restoration and mitigation plans, which will become increasingly important as human pressures on the estuary continue to grow.

Finally, very little is known concerning the spatial and temporal extent of hypoxic and anoxic conditions in the small tributaries of the York River Estuary. There is anecdotal evidence that low oxygen conditions occur in the tributaries and creeks of the estuary that can severely impact and degrade the benthic community (Gillett personal observation), but there is little direct, quantitative evidence. Given the spatial extent of these shallow tributaries and their high primary and secondary productivity, the impact of hypoxia-induced mortality on these areas could drastically reduce the ecosystem productivity of the estuary. The CBNERRS VA program would be well equipped to investigate these areas.

FINAL OBSERVATIONS ON THE BENTHOS OF THE YORK RIVER

The York River Estuary and the component NERRS sites comprise a large, complex ecosystem. The resident benthic fauna represent a wide array of trophic and taxonomic diversity. From well-known taxa like the eastern oyster *Crassostrea virginica* or the hard clam *Mercenaria mercenaria* to the relatively obscure harpactacoid copepods or capitellid polychaetes, benthic organisms play a vital role the functioning of the estuarine system. The benthic fauna of the York, Pamunkey, and Mattaponi rivers, like all of their biological resources, are still relatively non-disturbed compared to many parts of the Chesapeake Bay. That said, the benthic communities of the estuary will change and lose their ecological and economic value as the continuing developmental pressure within the estuarine watershed continues to increase, as it has in the coastal zone around the country (Beach, 2000; Pew Ocean Commission, 2003). The preservation and research of a diversity of benthic habitats by the Virginia CBNERRS program has been, and will continue to act as, part of the counterbalance to the forces of development in and along the York River Estuary. We have a rudimentary understanding of the functioning of the hidden and fascinating world of benthic fauna, but there is still much more for us to learn there.

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APPENDIX

A Partial Species List of Benthic Fauna Collected in the York River Estuary

Scientific name and the corresponding Integrated Taxonomic Information System Serial Code (TSN) where available.

Annelids

Aglaophamus verrilli	0066052
Almyracuma proximoculi	0066052
Amastigos caperatus	
Ampharetidae	0067718
Amphicteis floridus	0067753
Amphicteis gunneri	0067747
Ancistrosyllis commensalis	0065548
Ancistrosyllis hartmanae	0065543
Ancistrosyllis jonesi	0065544
Ancistrosyllis sp.	0065541
Asabellides oculata	0067786
Aulodrilus limnobius	0068682
Aulodrilus pigueti	0068680
Bhawania goodei	0065158
Bhawania heteroseta	0065159
Boccardiella ligerica	0067012
Branchiura sowerbyi	0068621
Brania wellfleetensis	0065762
Bratislavia unidentata	0069023
Cabira incerta	0065565
Calliobdella vivida	0069351
Capitella capitata	0067415
Capitella jonesi	
Capitellidae	0067413
Capitomastus aciculatus	0204558
Carazziella hobsonae	0067003
Caulleriella killariensis	0067131
Chaetopterus variopedatus	0067097
Cirratulidae	0067116
Clymenella torquata	0067528
Cossura longocirrata	0067207
Demonax microphthalmus	0068222
Dero digitata	0068904
Dero obtusa	0068907
Dero sp.	0068898
Diopatra cuprea	0066180
Dorvillea rudolphi	0066525
Drilonereis longa	0066426
Drilonereis sp.	0066423
Eteone heteropoda	0065266
Eteone lactea	0065267
Eumida sanguinea	0065343
Glycera americana	0066106
Glycera dibranchiata	0066107
Glycera sp.	0066102
Glycinde solitaria	0066132
Gyptis sp.	0065468
Gyptis vittata	0065470
Haber speciosus	0068745
Harmothoe extenuata	0064509
Harmothoe sp.	0064502
Helobdella elongata	0069397
Helobdella stagnalis	0069398
Heteromastus filiformis	0067420
Hirudinea	0069290
Hobsonia florida	0067755

Hydroides dianthus	0068282
Ilyodrilus templetoni	0068662
Isochaetides freyi	0068810
Laeonereis culveri	0065965
Leitoscoloplos fragilis	0066656
Leitoscoloplos robustus	0182728
Leitoscoloplos sp.	0066653
Lepidametria commensalis	0064703
Lepidonotus sublevis	0064610
Lepidonotus variabils	0064611
Levinsenia gracilis	0066729
Limnodriloides anxius	0158432
Limnodrilus hoffmeisteri	0068639
Limnodrilus profundicola	0068649
Limnodrilus sp.	0068638
Linopherus paucibracnchiata	0065175
Loimia medusa	0068015
Macroclymene zonalis	0067632
Maldanidae	0067515
Malmgreniella taylori	BAY0335
Manayunkia aestuarina	0068171
Marenzelleria viridis	0573739
Mediomastus ambiseta	0067439
Melinna maculata	0067766
Microphthalmus sczelkowii	0065477
Microphthalmus sp.	0065476
Monticellina dorsobrancialis	0204530
Mystides borealis	0065307
Myzobdella lugubris	0069316
Nais communis	0068950
Nais variabilis	0068959
Neanthes succinea	0065918
Nephtys incisa	0066028
Nephtys picta	0066030
Nephtys sp.	0066011
Nereidae	0065870
Nereis acuminata	0065926
Notomastus sp.	0067423
Oligochaeta	0068422
Orbiniidae	0066570
Paleanotus heteroseta	0065152
Parahesione luteola	0065493
Paranais frici	0068865
Paranaitis speciosa	0065321
Paraprionospio pinnata	0066937
Pectinaria gouldi	0067709
Phyllodoce arenae	0065366
Phyllodoce fragilis	0065337
Podarke obscura	0065517
Podarkeopsis brevipalpa	0065532
Podarkeopsis sp.	0065530
Pokarkeopsis levifuscina	0555698
Polycirrus eximius	0067963
Polydora cornuta	0204501
Polydora ligni	0066801
Polydora socialis	0066791
Polydora websteri	0066802
Prionospio perkinsi	0066854
Pristina breviseta	0068880
Pristinella jenkinae	0069030
Pristinella osborni	0069026
Pristinella sima	0069028
Pseudeurythoe paucibranchiata	0065176
Pseudeurythoe sp.	0065174
Quistradrilus multisetosus	0068794
Sabaco elongatus	BAY0341
Sabella microphthalma	0068223
Sabellaria vulgaris	0067671
Samythella elongata	0067802
Schistomeringos rudolphi	0066523
Scolelepis bousfieldi	0066944
Scolelepis sp.	0066942
Scolelepis squamata	0066943
Scolelepis texana	0066949
Scoloplos rubra	0066603
Sigambra bassi	0065554
Sigambra tentaculata	0065552
Spio setosa	0066868
Spiochaetopterus costarum	0067107
Spiochaetopterus oculatus	0067110
Spiophanes bombyx	0066897
Spirosperma ferox	0068610
Stephensoniana trivandrana	0069018
Sthenelais boa	0065084
Streblospio benedicti	0066939
Terebellidae	0067899
Tharyx acutus	0067147
Tharyx setigera	0067145
Tubifex sp.	0068622
Tubificidae	0068585
Tubificoides benedeni	0068592
Tubificoides brownae	0068688
Tubificoides diazi	0068689
Tubificoides gabriellae	0068590
Tubificoides heterochaetus	0068595
Tubificoides motei	
Tubificoides sp.	0068687
Tubificoides wasselli	0068692

Ascidians

Ascidiacea	0158854
Botryllus schlosseri	0159373
Molgula lutulenta	0159581
Molgula manhattensis	0159557

Chordates

Branchiostoma caribaeum	0159682
Branchiostoma virginiae	0206924

Cnidarians

Actiniaria sp.	0052485
Anthozoa	0051938
Ceriantheopsis americanus	0051992
Cerianthus americanus	0051987
Clytia cylindrica	
Diadumene leucolena	0052749
Ectopleura dumortieri	0719102
Edwardsia elegans	0052489
Haliplanella luciae	0204191
Halopteris tenella	
Hydrozoa	0048739
Obelia bidentata	0049532
Sertularia argentea	0049914

Crustaceans

Aegathoa medialis	0092440
Americamysis bigelowi	0682618
Ameroculodes sp.	0656551
Ampelisca abdita	0093329
Ampelisca macrocephala	0093322
Ampelisca sp.	0093321
Ampelisca vadorum	0093330
Ampelisca verrilli	0093331
Amphiodia atra	0157649
Amphitoidae	0093408
Balanoglossus aurantiacus	0158629
Balanus eburneus	0089621
Balanus improvisus	0089622
Batea catharinensis	0093528
Callinectes sapidus	0098696
Campylapsis rubicunda	
Caprella penantis	0095419
Cassidinidea lunifrons	0092347
Cerapus tubularis	0093587
Chiridotea almyra	0092638
Chiridotea coeca	0092640
Chiridotea nigrescens	0092642
Corophium acherusicum	0093590
Corophium insidiosum	0093600
Corophium lacustre	0093594
Corophium simile	0093595
Corophium sp.	0093589
Corophium tuberculatum	0093596
Corophium volutator	0093601
Cyathura burbancki	0092150
Cyathura polita	0092149
Cyclaspis varians	0091033
Cymadusa compta	0093430
Decapoda	0095599
Diastylis polita	0090858
Dyspanopeus sayi	0098901
Edotea triloba	0092627
Elasmopus laevis	0093761
Erichsonella attenuata	0092618
Erichsonella filiformis	0092619
Erichthoneus brasiliensis	0093613
Eurypanopeus depressus	0098759
Exosphaeroma	0092301
Gammarus daiberi	0093779
Gammarus mucronatus	0093783
Gammarus palustris	0093782
Gammarus sp.	0093773
Gammarus tigrinus	0093781
Gilvossius setimanus	0552843
Hargeria rapax	0092068
Harpactocoida	
Hutchinoniella taylori	0083682
Hyalella azteca	0094026
Idoteidae	0092564
Idunella smithii	BAY0133
Lepidactylus dytiscus	0093998
Leptocheirus plumulosus	0093486
Leucon americanus	0090790
Listriella barnardi	0094213
Listriella clymenellae	0094214
Melita appendiculata	0093813
Melita nitida	0093812
Microprotopus raneyi	0094122
Monocorophium tuberculatum	0656762
Monoculodes edwardsi	0094539
Monoculodes intermedius	0094536
Neomysis americana	0090062
Ogyrides alphaerostris	0096737
Oxyurostylis smithi	0090923
Palaeomonetes pugio	0096390
Panopeus herbstii	0098778
Paracaprella tenuis	0095434
Parametopella cypris	0094927
Paraphoxus spinosus	0094756
Parapleustes estuarius	BAY0199
Pinnixa chaetopterana	0098998
Pinnixa retinens	0099001
Pinnixa sayana	0099002
Pinnixa sp.	0098993
Pleusymtes glaber	0094797
Polyonyx gibbesi	0098083
Ptilanthura tenuis	0092155
Rhithropanopeus harrisi	0098790
Sarsiella texana	0084276
Sarsiella zostericola	0084277
Sphaeroma quadridentatum	0092339
Squilla empusa	0099143
Stenothoe minuta	0094936
Unciola irrorata	0093632
Unciola serrata	0093633
Unciola sp.	0093629
Unionicola	0083073
Upogebia affinis	0098209
Xanthidae	0098748

Echinoderms

Holothuroidea	0158140
Leptosynapta tenuis	0158432
Microphiopholis atra	BAY0347

Echiurians

Echiura	0154972
Thalassema hartmani	0155119
Thalassema sp.	0155118

Ectoprocts

Anguinella palmata	0155542
Bowerbankia gracilis	0155559
Conopeum tenuissimum	
Ectoprocta	0155470
Membranipora tenuis	0155827
Pedicellina cernua	0156740

Foraminifera

Miliammina fusca	0044215

Hemichordates

Hemichordata	0158616
Saccoglossus kowalevskii	0158626

Insects

Ablabesmyia annulata	0128081
Ablabesmyia parajanta	0128112
Bezzia sp.	0012778
Ceratopogonidae	0127076
Chaoborus albatus	0125905
Chaoborus punctipennis	0125923
Chaoborus sp.	0125904
Chironomidae	0127917
Chironomini sp.	0129229
Chironomus sp.	0129254
Cladopelma sp.	
Cladotanytarsus mancus	
Cladotanytarsus sp.	
Clinotanypus pinguis	0127998
Coelotanypus sp.	0128010
Coleoptera sp.	0109216
Cricotopus sp.	0128575
Cryptochironomus fulvus	0129376
Cryptochironomus parafulvus	0129382
Cryptochironomus sp.	0129368
Cryptotendipes sp.	0129394
Demicryptochironomus	0129421
Dicrotendipes nervosus	0129452
Ephemeroptera	0100502
Epoicocladius sp.	0128682
Glyptotendipes sp.	0129483
Gomphidae	0101664
Harnischia sp.	0129516
Hexagenia limbata	0101552
Hexagenia sp.	0101537
Nanocladius sp.	0128844
Oecetis inconspicua	0116613
Oecetis sp.	0116607
Palpomyia sp.	0127859
Paralauterborniella sp.	0129616
Paratendipes sp.	0129623
Polypedilum convictum	0129671
Polypedilum fallax	0129676
Polypedilum flavum	
Polypedilum halterale	0129684
Polypedilum illinoense	0129686
Polypedilum scalaenum	0129708
Polypedilum sp.	0129657
Polypedilum sp.	0129657
Probezzia sp.	0127729
Procladius sp.	0128277
Procladius sublettei	0128316
Pseudochironomus fulviventris	0129858
Pseudochironomus sp.	0129851
Sialis sp.	0115002
Simulium sp.	0126774
Sphaeromias	0127761
Stictochironomus devinctus	0129790
Stictochironomus sp.	0129785
Tanypodinae	0127994
Tanypus neopunctipennis	0128329
Tanypus sp.	0128324
Tanytarsini sp.	0129872
Tanytarsus sp.	0129978
Trichoptera	0115095
Xenochironomus festivus	0129841
Xenochironomus sp.	0129837
Zygoptera	0102042

Molluscs

Acteocina canaliculata	0076117
Aligena elevata	0080685
Anachis obesa	0073622
Anadara ovalis	0079342
Anadara transversa	0079340
Anomia simplex	0079798
Barnea truncata	0081798
Bivalvia	0079118
Boonea bisuturalis	0075987
Busycon canaliculatum	0074097
Corbicula fluminea	0081387
Corbicula manilensis	0081386
Crassispira ostrearum	0074901
Crassostrea virginica	0079872
Cratena kaoruae	0078714
Crepidula convexa	0072624
Crepidula fornicata	0072623
Cylichna alba	0076148
Cyrtopleura costata	0081796
Doridella obscura	0078439
Ensis directus	0081022
Epitonium multistriatum	0072247
Epitonium rupicola	0072249
Epitonium sp.	0072233
Eupleura caudata	0073300
Gastropoda	0069459
Gemma gemma	0081511
Geukensia demissa	0079555
Haminoea solitaria	0076258
Hydrobia	0070494
Littoridinops tenuipes	0070528
Littorina littorea	0070419
Lucina multilineata	0080389
Lyonsia hyalina	0081926
Macoma baltica	0081052
Macoma mitchelli	0081054
Macoma sp.	0081033
Macoma tenta	0081055
Mangelia plicosa	0074568
Mercenaria mercenaria	0081496
Mitrella lunata	0073552
Mulinia lateralis	0080959
Musculium	0081427
Mya arenaria	0081692
Nassarius obsoletus	0074111
Nassarius vibex	0074107
Nucula proxima	0079132
Nuculana messanensis	0079212
Nudibranchia	0078156
Odonata	0101593
Odostomia bisuturalis	0075988
Odostomia engonia	0075504
Odostomia sp.	0075447
Parvilucina multilineata	0080388
Petricola pholadiformis	0081627
Pisidium sp.	0081400

Polinices duplicatus	0072918
Polymesoda caroliniana	0081383
Pyramidella candida	0075948
Rangia cuneata	0080962
Rapana venosa	
Rictaxis punctostriatus	0076083
Sayella chesapeakea	0070946
Sphaeriidae	0112737
Sphaerium sp.	0081391
Tagelus divisus	0081274
Tagelus plebeius	0081272
Tellina agilis	0081088
Tellina versicolor	0081100
Tellinidae	0081032
Tenellia sp.	0078547
Turbonilla interrupta	0075687
Turbonilla sp.	0053964
Turridae	0074555
Unionidae	0079913
Urosalpinx cinerea	0073264
Yoldia limatula	0079273

Nematodes

Anticoma litoris	0062032
Axonolaimus spinosus	0059512
Cylindrotheristus oxyuroides	0060433
Desmodora sp.	0060744
Euchromadora sp.	0061205
Mesotheristus setosus	0060526
Metachromadora parasitifera	0060715
Metalinhomeus retrosetosus	
Metalinhomeus typicus	
Nematoda	0059490
Neotonchus punctatus	0061519
Oncholaimus sp.	0062449
Pamponema sp.	
Paracanthonchus sp.	0061480
Paramonhystera proteus	
Parodontophora brevamphida	0059569
Ptycholaimellus ponticus	0061468
Sabatieria pulchra	0061095
Sphaerolaimus balticus	
Steineria sp.	0191219
Thalassoalaimus sp.	0062146

Nemerteans

Carinomidae	0057427
Cerebratulus sp.	0057446
Nemertea	0057411

Ostracods

Ostracoda	0084195

Phoronids

Phoronida	0155456
Phoronis psammophila	0155467
Phoronis sp.	0155462

Platyhelminthes

Euplana gracilis	0054139
Stylochus ellipticus	0054089

Poriferans

Cliona sp.	0048523
Halichondria bowerbanki	0048398
Haliclona loosanoffi	0047774
Haliclona spp.	0047771
Lissodendoryx carolinesis	0048072
Microciona prolifera	0047997

Pycnogonids

Anoplodactylus lentus	0083644
Pycnogonida	*0083545*

Sipunculids

Sipuncula	0154520

Fisheries of the York River System

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ABSTRACT

The York River system supports a diverse fish fauna represented by members of the shad and herring family, drums, flatfishes, temperate basses, catfishes, sharks, skates, rays, and numerous smaller fishes that serve as forage such as bay anchovy, Atlantic menhaden, and killifish. Historically, fisheries for blue crabs, American shad, striped bass, and Atlantic sturgeon thrived in the Chesapeake Bay region but in recent times, and with the exception of striped bass, these fisheries have declined. Fishes of the York River exhibit divergent life history patterns, from fast growing, highly fecund species such as alewife, to slow growing, late-maturing species with low fecundity such as Atlantic sturgeon. The young of many species use the York River system as a nursery area and depend on the high productivity of this estuary for conferring fast growth and high survival during the first year of life. Habitat alterations that result in loss of water quality or quantity may deleteriously affect recruitment of young fishes through direct effects on young-of-the-year fish survival, or through disruption of spawning activity (e.g., dam construction, and water withdrawals that affect salinity and flow). Continued monitoring of recruitment success is crucial to understanding population-level responses to environmental and human-induced perturbations, especially in light of the projected growth of the human population in this watershed. Other important areas of continued research include assessment of habitat use and delineation of trophic interactions.

INTRODUCTION

The York River system is home to a diversity of fish species, some are year-round residents and others use the river during a particular season or life stage. Year-round residents, such as hogchoker and gizzard shad, move within areas of the river to make short spawning migrations or to find optimal water temperatures. Anadromous fish, such as American shad and striped bass, enter the York River system to spawn in spring, and the larval and juvenile stages use the shorelines of the fresh and brackish waters of the system as nursery grounds. Summer visitors to the York River (e.g., Atlantic croaker, spot, and weakfish) use the estuary as a nursery for juveniles and as foraging grounds for adults.

The Chesapeake Bay, positioned at the intersection of boreal and tropical regimes, serves as temporary and permanent habitat to a diversity of fish species. The York River's location near the mouth of the Chesapeake Bay allows for a number of marine species to use the system, in addition to the freshwater inhabitants found upstream. The VIMS Juvenile Fish Survey has been assessing fish populations in the York River since 1955, and has observed more than 130 fish species in the York River. These species include top predators such as sharks, as well as plankton feeders such as bay anchovies. The following sections describe many important fishes of the York River system and includes a description of the blue crab and its fishery because of the historical importance of this invertebrate fishery to Chesapeake Bay.

FISH GROUPS COMMON TO THE YORK RIVER SYSTEM

Shads and Herrings

The York River is home to several species in the shad and herring family (Clupeidae). Many of these species are anadromous, migrating into the York River and its tributaries to spawn in the freshwater reaches each spring. Several members of this family are important to commercial, recreational, and subsistence fishers.

American shad, *Alosa sapidissima*, have been harvested in Virginia for their meat and roe for centuries. Native Americans caught shad with seines made from bushes, as well as spears (ASMFC, 2007); European colonials also discovered and harvested this resource. Modern gears used to capture shad include pound nets, haul seines, fyke nets, staked gill nets, drift gill nets, and hook and line. Gill nets (Figure 1) are the preferred gear and have historically yielded the highest catches of American shad (Nichols and Massman, 1963). Because of the magnitude of the harvest, the shad stock has plummeted since its colonial heyday. Catches in 1897 were 11.5 million pounds compared with less than 1 million pounds in 1982 (ASMFC, 1999). To halt further declines of the American shad population in Virginia, a fishing moratorium on recreational and commercial harvest of American shad in the Chesapeake Bay and its tributaries was imposed in 1994. During the same year, the United States Fish and Wildlife Service (USFWS) and the Virginia Department of Game and Inland Fisheries (VDGIF) initiated a hatchery-restocking effort in the James and Pamunkey rivers using shad

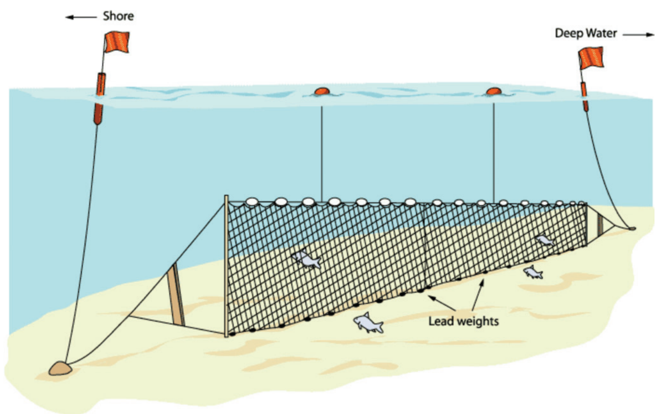

Figure 1. Gill net commonly used to catch shad and other fishes in the York River. (Figure courtesy of Michigan Sea Grant. http://www.miseagrant.umich.edu/nets/largegill.html)

broodstock taken from the Pamunkey River (Olney *et al.*, 2003). Current fish stocking efforts are conducted by VDGIF/USFWS and the Pamunkey and Mattaponi tribal governments. The Pamunkey and Mattaponi tribes, who have retained their rights to harvest this resource, stock 3-6 million fry to their respective rivers each year. This stocking of shad supplements the million (or more) shad fry stocked in the Pamunkey River by the VDGIF (T. Gunter, pers. comm.) The coastal fishery for American shad has been closed in Virginia waters since 2004 (ASMFC).

Current research efforts in the York River system seek to monitor abundance of both adult and juvenile American shad. VIMS has conducted staked gillnet monitoring of adult American shad each spring (during the spawning season) since 1998. Formerly, juvenile abundance was monitored using push-nets (1979-1986, 1991-2002), but now such data are collected from the VIMS Juvenile Striped Bass Seine Survey (Wilhite *et al.*, 2003). Results from these surveys show that the York River system has the highest index of abundance for juvenile shad compared with the James and Rappahannock rivers, thus highlighting the importance of the York River's shad runs to the Virginia Chesapeake Bay stock.

Adult American shad enter the York River in the spring to spawn in the fresh waters of the tributaries. Most of these spawners return to their natal stream, spend approximately 30 days in the area (Aunins, 2005, Olney *et al.*, 2006), then migrate to waters off the Gulf of Maine where they are found in summer and fall. Eggs have been collected between Mattaponi River km 81 and 124 and Pamunkey River km 98 and 150 (upstream of Sweet Hall Marsh). American shad larvae have been collected at the Sweet Hall Marsh area and upriver (Bilkovic *et al.*, 2002). The young of the year reside in fresh or brackish waters until fall when they leave the rivers. Most juvenile (Figure 2A) and adult shad overwinter in offshore waters, but some young of the year overwinter near the bay mouth.

American shad are filter feeders, eating planktonic shrimp and copepods, as well as fish larvae (Walter and Olney, 2003, Hoffman *et al.*, 2007). In the York estuary, mysid shrimp (*Neomysis americana*) are the primary food item of the adult spawners (Walter and Olney, 2003).

Hickory shad, *Alosa mediocris*, also spawn in freshwater during the spring. Adults return to the ocean in mid-summer after spawning, whereas juveniles move downstream into brackish or salt water and may remain there until autumn when they migrate offshore. Hickory shad are repeat spawners, with a smaller autumn spawning run. They eat crustaceans, fish eggs, squids, and small fishes (Murdy *et al.*, 1997).

Alewife (*Alosa pseudoharengus;* Figure 2B) and blueback herring (*Alosa aestivalis*) sometimes school together, and are thus collectively known as "river herring." Like American and hickory shad, these herrings spawn in spring in the freshwater reaches of the York River system. Alewives spawn in shallow, sluggish waters in late March and April, whereas blueback herring spawn in swifter waters later in the spring (April and May); adults move offshore after spawning. Juveniles of both species migrate from fresh or brackish waters to the ocean in early fall. Some remain in bay waters over winter. These herrings prey on planktonic organisms, such as diatoms, copepods, ostracods, shrimps, amphipods, as well as insects, small fishes, squids, and fish eggs (Murdy *et al.*,1997).

Historically, river herring, like shad, were targeted by both river and ocean fisheries. Coastwide commercial landings of river herring decreased from the early 1970s to the 1990s (Klauda *et al.*, 1991, ASMFC, 1999). Historically, Virginia landings accounted for a large portion of total Chesapeake Bay landings (Klauda *et al.*, 1991). River herring are sought by recreational netters who practice "dipping"—holding a large net on the bottom and lifting it sporadically—during the spawning runs. Juvenile abundance of these two species in the York River system has been generally low since the 1990s. Juvenile alewives are less abundant than juvenile blueback herring in both the Pamunkey and Mattaponi rivers (VIMS Juvenile Striped Bass Seine Survey).

Gizzard or mud shad, *Dorosoma cepedianum*, do not undergo extensive spawning migrations. Gizzard shad inhabiting the brackish waters of the estuary move to fresh water to spawn in late spring or early summer. In fall and winter, they live closer to the mouth of the river. As their name suggests, these fish are found in soft bottom habitats, as well as near sand, gravel and vegetation in fresh and brackish water. Gizzard shad eat algae, crustaceans, and other organisms found on the bottom (Murdy *et al.*, 1997).

Atlantic menhaden, or bunker (*Brevoortia tyrannus*), first enter the York River system as larvae in November and early spring. Young fish move to brackish and fresh waters in May and June. In fall, the young of the year leave the bay and move to deeper waters. Some juveniles (Figure 2C) overwinter in the bay. Spawning occurs in shelf waters in spring and fall. Atlantic menhaden swim in schools and feed on phytoplankton and zooplankton (Murdy *et al.*, 1997).

Figure 2. Juvenile clupeids. A-American shad, B-Alewife, C-Atlantic menhaden (Photos courtesy of VIMS Juvenile Fish Survey)

Atlantic menhaden have been harvested in Chesapeake Bay for hundreds of years. These protein-rich oily fish were used by Native Americans as fertilizer. In the 20th century, menhaden meal and oil were used in animal feeds and various manufactured goods such as soap and linoleum. The current Atlantic commercial fishery captures menhaden for reduction (or processing) and bait. In Virginia, these fisheries operate in the Chesapeake Bay and nearby coastal waters. Atlantic menhaden landings in Virginia account for a high percentage of Atlantic menhaden landings coast wide (ASMFC, 2001, ASMFC, 2005(b)).

Threats to shad, herring, and menhaden include overfishing, habitat degradation (particularly water quality changes due to nutrient and sediment loading), and pollution. The anadromous members of this family are threatened by the addition of dams, which can prevent them from reaching their spawning grounds. If positioned in key locations, water withdrawal facilities—such as reservoir intakes—may pose a threat to freshwater spawners in terms of egg and larval losses.

Drums

Members of the family Sciaenidae, collectively referred to as drums, are important members of the York River fish community and include Atlantic croaker, spot, weakfish, spotted seatrout, and silver perch. Drums are mainly found in coastal and estuarine areas, but may be found in a variety of habitats including freshwater. Most species migrate seasonally along the coast and use Chesapeake Bay and the York River for feeding and as a nursery area. Drums are best known for their ability to produce drumming or croaking sounds using their specialized swim bladder and associated musculature.

Adult Atlantic croaker, *Micropogonias undulatus*, spawn offshore in winter and move into the York River in the late spring. They remain in the river until fall when they migrate back offshore. Young-of-the-year croaker move into the York River estuary in summer and fall and inhabit low salinity waters and freshwater creeks. The young fish overwinter in the deeper portions of the river, where they remain until the following fall when they migrate to the ocean with the adults (Murdy *et al.*, 1997).

Atlantic croaker is one of Virginia's most important fishery resources. Adults (Figure 3A) are captured by a variety of fishing gear including gill nets, pound nets, and haul seines. The abundance of this species can vary dramatically from year to year and commercial catches reflect this variation. Since 1950, commercial landings in Virginia ranged from 6,200 pounds to over 14,000,000 pounds (http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html). Extremely cold winters with low water temperatures (<3°C) can cause high mortality of juveniles, and therefore recruitment to the adult stock is mainly determined by environmental conditions during the first winter (Norcross, 1983; Lankford and Targett, 2001). Management efforts focus on maintaining the stock biomass above a target level so that stock abundance can rebound after periods of low recruitment (ASMFC, 2005a).

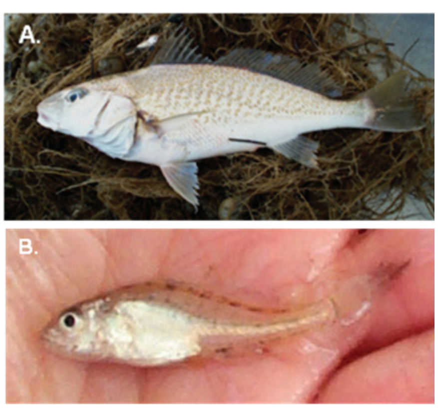

Figure 3. A-Adult Atlantic croaker, B-Juvenile Atlantic croaker (Photos courtesy of VIMS Juvenile Fish Survey)

Atlantic croaker are demersal (bottom-dwelling) fish. Adults can be found over sandy or muddy substrate often associated with submerged aquatic vegetation (ASMFC, 2004). Juveniles (Figure 3B) use the upper portion of the York River estuary where salinities are more stable and where turbidity is higher and organic matter and associated prey are more available (ASMFC, 2005a). Adults feed opportunistically on many types of invertebrates, such as polycheate worms, and even small fishes (Parthree *et al.*, 2006).

Spot, *Leiostomus xanthurus*, (Figure 4) undertake seasonal migrations from estuarine and coastal waters to offshore spawning grounds in winter. In the spring, adults and juveniles enter the York River where they remain until fall when they migrate south along the coast to Cape Hatteras. Adult spot are mainly found in the lower York River where salinity is higher, but juveniles move upriver to lower salinity tidal creeks, such as Taskinas creek, as well as freshwater areas in the Mattaponi and Pamunkey rivers.


Figure 4. Spot (Photo courtesy of VIMS Juvenile Fish Survey)

Spot are harvested by both commercial and recreational fishers. Spot population abundance fluctuates annually in response to environmental factors that contribute to larval and juvenile mortality.

Spot are bottom feeders as adults and feed nocturnally on invertebrates such as small crustaceans and mollusks. Juvenile spot feed mainly on zooplankton before becoming bottom feeders (Murdy *et al.*, 1997, ASMFC, 2005a).

Weakfish or grey trout, *Cynoscion regalis*, migrate seasonally along the Atlantic coast, moving into Chesapeake Bay and the York River in the spring and migrating to coastal waters in the fall, when they can be found in large aggregations. The adults spawn near the Bay mouth and in nearshore areas beginning in the spring and continuing through the summer. Young-of-the-year grey trout (Figure 5) can be found in low-salinity habitats in the York River in summer. Growing rapidly, juvenile grey trout move to more saline waters by late fall and in early winter, these juveniles leave the York River. Weakfish feed on a variety of fish and crustaceans and become more piscivorous as they grow older (Murdy *et al.*, 1997, ASMFC, 2004).


Figure 5. Young-of-the-year weakfish (Photo courtesy of VIMS Juvenile Fish Survey)

Silver perch, *Bairdiella chrysou-*

ra, (Figure 6) are found in the Bay throughout the year, but are most abundant in the York River from April to November. They spawn in nearshore areas of the eastern shore, both bayside and seaside; juveniles are usually abundant in shallow sea grass beds. Silver perch in the York River eat bay anchovies, mysids, blue crabs and a variety of other animals including other fishes and invertebrates (Parthree *et al.*, 2006).

Figure 6. Young-of-the-year silver perch (Photo courtesy of VIMS Juvenile Fish Survey)

Adult spotted seatrout or speckled trout, *Cynoscion nebulosus*, are found in the York River from April to November. They spawn near the mouth of the Bay and in nearshore coastal waters from May to July. Juvenile spotted seatrout are found in the York River system from summer to fall in intertidal creeks and marshes near submerged aquatic vegetation. This species can withstand a large range of salinities and is a popular target for recreational anglers fishing near seagrass beds (Murdy *et al.*, 1997). Large areas of submerged aquatic vegetation are important habitat for adult spotted seatrout.

The diet of juvenile spotted seatrout is comprised mainly of crustaceans, but as fish age, the diet shifts to penaeid shrimp and other fish species like mullet (Murdy *et al.*, 1997).

Flatfishes

Flatfishes in the order Pleuronectiformes are characterized by adults that lie flat on the bottom on one side of their body. At the beginning of their life, flatfish are bilaterally symmetrical and larvae live in the middle of the water column, but during development, larvae metamorphose to the compressed shape of the adult. During metamorphosis, the eyes and other sensory organs migrate to one side of the head and the fish becomes bottom dwelling. The dorsal side is usually pigmented and the ventral side (the blind side) is usually unpigmented. Flatfishes are referred to as either righteyed or lefteyed: lefteye flatfish lie on their right side and both eyes are on the left side of the head. The opposite is true for righteye flatfish. This character is consistent within a family (Helfman *et al.*, 1997). Representatives from five families of flatfishes can be found in the York River, and three of those families are represented by a member that is commonly encountered.

Summer flounder, *Paralichthys dentatus*, (Figure 7A) is a lefteye flounder and a popular sport fish in the lower York River. Adult summer flounder are migratory and spend the winter months offshore on the outer continental shelf. Summer flounder are found in the Bay and lower portion of the tributaries from spring to autumn. Spawning occurs during the offshore migration from late summer to mid-winter (Murdy *et al.*, 1997). Adults and juveniles in the York River prefer sandy habitats, but can also be found near eel grass beds or in marsh creeks. Adults spend most of their life burrowed in the substrate and can change their coloration to match the surrounding substrate (ASMFC, 2004, Murdy *et al.*, 1997). Summer flounder in the York River eat mostly fish (e.g., bay anchovy and spot) along with some invertebrates like mysids (Parthree *et al.*, 2006).

The hogchoker, *Trinectes maculatus*, (Figure 7B) is a small, ubiquitous righteye flatfish (maximum size 20 cm total length) that is a year-round resident of Chesapeake Bay and the York River. This species is the second most frequently captured in the VIMS Juvenile Fish Survey. Hogchokers can be found in all salinities from true freshwater to the marine environment and are often found on muddy substrates. Spawning takes place at night beginning in late spring and continues through late summer (Smith, 1986).

Hogchokers are exclusively bottom feeders, feeding on a wide range of invertebrates including amphipods, polycheates, dipteran larvae, and ostracods (Smith, 1986).

The blackcheek tonguefish, *Symphurus plagiusa*, a teardrop-shaped lefteye flatfish, is found in the York River and lower Chesapeake Bay throughout the year. It inhabits soft muddy bottoms and feeds on mollusks, worms, and small crustaceans (Murdy *et al.*, 1997). This species spawns in the Bay from late spring through summer.

Striped Bass and White Perch

Two species in the family Moronidae, known as temperate basses, inhabit the York River. White perch are year-round residents, whereas striped bass migrate into the river in spring as adults, but young striped bass (<4 years) are found in the estuary throughout the year.

White perch, *Morone americana*, (Figure 8A) tolerate a wide range of salinities and are found from the Bay to the upper reaches of the Pamunkey and Mattaponi rivers, though they prefer salinities around 18 ppt (parts per thousand). White perch undertake short migrations upstream to spawn from April to June. Juveniles use the shoreline areas of the Mattaponi, Pamunkey and upper York rivers as nursery habitat and their occurrence often overlaps with juvenile striped bass. White perch are a popular target for recreational anglers.

Adults feed on small fishes, crustaceans and shrimps, whereas juveniles feed mostly on aquatic insects and small crustaceans.

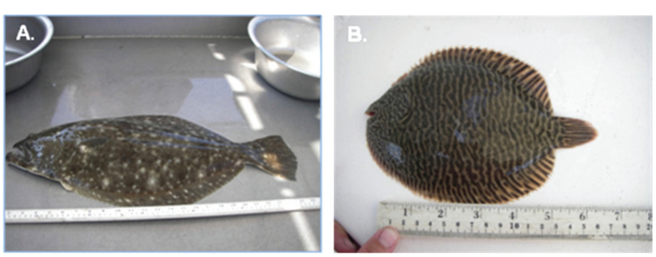

Figure 7. A-Summer flounder, B-Hogchoker (Photos courtesy of VIMS Juvenile Fish Survey)

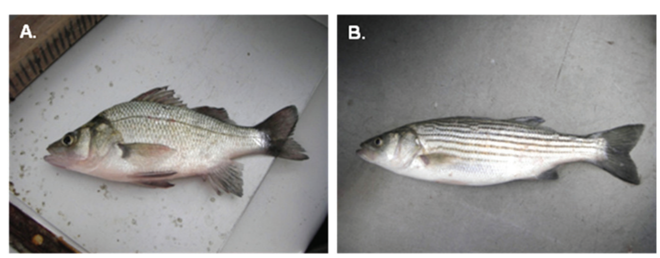

Figure 8. A-White perch, B-Striped bass (Photos courtesy of VIMS Juvenile Fish Survey)

Striped bass, *Morone saxatilis*, (Figure 8B) use the fresh waters of the Pamunkey and Mattaponi rivers as spawning grounds in early spring. After spawning, adults depart the bay and complete coastal migrations towards the north, returning in fall. Young-of-the-year striped bass inhabit brackish waters downstream from spawning grounds until fall when they migrate to deeper waters in the bay. The Virginia Institute of Marine Science's Juvenile Striped Bass Survey monitors the annual recruitment of striped bass in Virginia's tributaries to Chesapeake Bay, including the York, Pamunkey, and Mattaponi rivers. The Pamunkey River, including Sweet Hall Marsh, is an important spawning and nursery area for this species (Bilkovic *et al.*, 2002).

Young-of-the-year striped bass consume invertebrates such as copepods, shrimps, worms, insects, and insect larvae, as well as fish eggs and larvae (Muffelman, 2006). Adult and juvenile striped bass prey upon a variety of fishes, including anchovies, fishes in the drum family (croaker, spot, etc.), Atlantic menhaden, and invertebrates (Walter and Olney, 2003).

Catfishes

Several species of native and introduced catfish in the family Ictaluridae inhabit the York River and its tributaries (Figure 9). Catfish in this family can be easily identified due to several unique characteristics. Four pairs of barbels ("whiskers") around the mouth have given rise to the common name (Murdy *et al.*, 1997). Catfish lack scales and have a fleshy fin called an adipose fin that is just anterior to caudal fin. These fish are sought mostly by recreational anglers in the York River. Growth rates of the channel, white, and blue catfish are higher in the York River system than in other Chesapeake Bay tributaries in Virginia (Connelly, 2001).

Figure 9. Blue catfish (top panel), channel catfish (middle panel), white catfish (bottom panel) (Photos courtesy of VIMS Juvenile Fish Survey)

White catfish, *Ameiurus catus*, are native to all tributaries of Chesapeake Bay and are abundant in the York River system. They tolerate a wide range of salinities, although white catfish are most commonly found in freshwater. During spawning in early summer, eggs are deposited in a saucer-shaped nest that is constructed by the parents. One or both parents will guard the eggs and young in the nest. This species eats a variety of bottom-dwelling insects and crustaceans as well as fishes.

Channel catfish, *Ictalurus punctatus*, are not native to the York River. They were introduced to the major tributaries of Chesapeake Bay in the 1890s and are now common in the York, Pamunkey, and Mattaponi rivers (Connelly, 2001). The adults are found in deep pools near structure or cover such as submerged logs. Channel catfish spawn in fresh or low salinity waters in the late spring when water temperatures are near 24°C. Eggs are laid in a nest which can consist of an undercut stream bank, hollow log, crevice or even manmade containers (Murdy *et al.*, 1997). One or both parents guard the young while in the nest and upon hatching, the young stay together in tight aggregations near suitable cover. Channel catfish are opportunistic bottom feeders that will eat a variety of aquatic insects and insect larvae, fishes, and crabs.

Blue catfish, *Ictalurus furcatus*, are not native to Virginia. They were introduced to the Mattaponi River in 1985 and are now established in both the Mattaponi and Pamunkey rivers (VIMS Juvenile Fish Survey, unpublished data). This species inhabits brackish waters, but is mainly found in the main channels of large rivers where salinities are below 12 ppt. Blue catfish spawn during the late spring when water temperatures are at least 21°C. Males build nests in cavities of submerged logs or undercut banks and guard the eggs and newly hatched young until the young leave the nest.

This species is a popular sport fish for recreational anglers and will strike at a variety of live and artificial baits. Blue catfish are scavenging carnivores and in the York River system they eat benthic crustaceans, such as crabs and amphipods; clams; and fishes, such as Atlantic menhaden and gizzard shad (Parthree *et al*., 2006).

Other Important Fishes

The fish community of the York River is diverse and some of the common species are not well known by the public, but they play an important role in the ecosystem.

Bay anchovy, *Anchoa mitchilli*, (Figure 10) are an abundant year-round resident of the lower York River. Bay anchovy are a schooling species that are found in deeper water in the winter and in shallow areas along shorelines in the summer. They spawn at night in estuaries from spring to late summer with peak spawning occurring in July. Bay anchovy feed mainly on zooplankton, such as copepods and other crustaceans.

Figure 10. Bay anchovy (Photo courtesy of VIMS Juvenile Fish Survey)

Bay anchovy have no commercial or recreational value; however, they are an important food resource for numerous other fish species (e.g., striped bass and summer flounder) that inhabit the York River, thus making them an important component of the food web. Bay anchovy abundance and recruitment are highly variable from year to year and are controlled by complex environmental and biological processes (JUNG and HOUDE, 2004).

The oyster toadfish, *Opsanus tau*, is commonly found year-round in the lower to middle reaches of the York River. It is easily identified because of its broad head and wide mouth with fleshy protrusions, and slimy, scaleless skin. The male produces vocalizations during the spawning season (April to October) to attract females to a nest (usually shells or even old cans or jars), where the female deposits large eggs and then leaves the male to fertilize and guard them.

Both juvenile and adult oyster toadfish are bottom dwelling and feed on a variety of crustaceans, mollusks, and fish. They are often caught by hook and line and are safe to eat but are not consumed due to the sharp teeth and perceived difficulty in handling.

The spotted hake, *Urophycis regia*, is a member of the cod family. Juveniles inhabit the lower bay and its estuaries, including the York River, from March to June. As water temperatures warm, spotted hake move offshore. Adults spawn offshore from late summer to winter. Spotted hake consume crustaceans, fishes, and squids.

The American eel, *Anguilla rostrata*, is a catadromous species with a complex life cycle (Figure 11); eels spend their adult life in freshwater ponds, streams, and brackish water. Adult

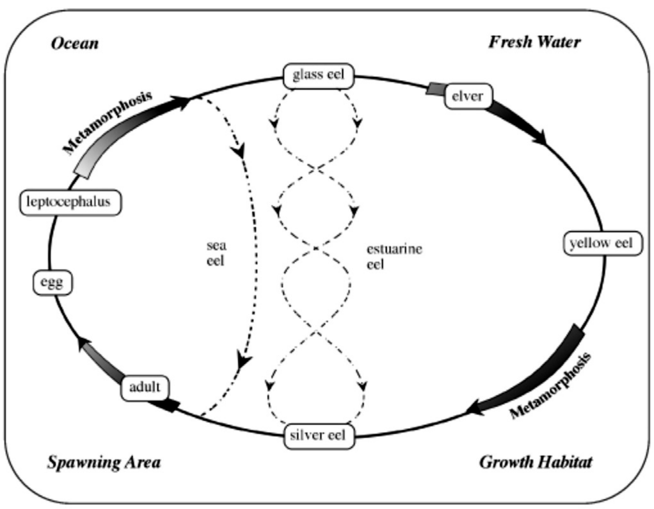

Figure 11. American eel life cycle. (Figure courtesy of Department of Fisheries and Oceans Canada, Underwater World factsheet)

eels leave these habitats to migrate to the Sargasso Sea to spawn in late winter to early spring. Young eels begin their life as leptocephalus larvae and drift on ocean currents for up to one year before entering Chesapeake Bay and the York River. Just before they enter the estuary, the larvae metamorphose into the "glass eel" stage, called such because they are transparent. The glass eels become pigmented as they migrate upstream and are then called elvers. Elvers and later stage adult eels called yellow eels inhabit a diversity of habitats in the York River system from brackish marshes to freshwater ponds.

Eels play an important role in the York River ecosystem. Adults feed nocturnally on a diet of insects, worms, crustaceans and fish, and eels of all sizes are preyed upon by other fish and fish-eating birds and mammals. They are harvested commercially for bait and for export to Asia and Europe, and recreational anglers catch them to use as bait for popular game fish such as striped bass and cobia. Recent declines in the commercial harvest of American eels throughout their range have raised concerns about the status of the population. State and federal agencies are now closely monitoring commercial landings and the recruitment of juvenile eels to help assess the status of the stock and establish sustainable harvest limits.

Striped killifish, *Fundulus majalis*, are very common and abundant in the lower York River throughout the year. They inhabit sandy-bottom shallow habitats with relatively high salinities and are not found in freshwater. Males and females of this species differ in their coloration. Males have 15 to 20 black vertical bars on their sides, whereas females have 2 or 3 black horizontal stripes and a few vertical bars near the caudal fin. Striped killifish feed on invertebrates such as polycheate worms and insects, and serve as food for other fishes and wading birds (MURDY *et al.*, 1997).

Mummichogs, *Fundulus heteroclitus*, are an abundant year-round resident of the marshes and creeks of the York River system. They prefer salinities lower than the striped killifish, but the two species are often collected together where their distributions overlap. The mummichog diet is varied and includes many types of mollusks, insects, plants, and occasionally other fishes (MURDY *et al.*, 1997). They are sold as bait (minnows) for recreational anglers and are food for other fishes and wading birds.

The Atlantic sturgeon is a member of an ancient family of fishes (Acipenseridae) thought to have been on Earth for more than 120 million years. The Atlantic sturgeon consists of two subspecies (ONG *et al.*, 1996): *Acipenser oxyrinchus oxyrinchus,* the subspecies that spawns in the Chesapeake Bay and ranges from Labrador to northern Florida, and *Acipenser oxyrinchus desotoi,* also known as the gulf sturgeon, which inhabits the Gulf of Mexico. All populations of Atlantic sturgeon are anadromous, thus they are dependent on freshwater tributaries for spawning and nursery habitats. In mid-Atlantic latitudes, spawning occurs between May and July over hard bottom in regions of adequate flow. Hard substrates provide good adhesion for the sticky eggs and sufficient flow keeps the eggs well oxygenated and prevents them from burial by settling sediments. The exact location of spawning grounds in the Chesapeake's tributaries is unknown. Currently, there is an effort to locate, protect and restore these areas in the James River where historic populations were very large, but this effort has not yet expanded into the York River watershed.

The Atlantic sturgeon (Figure 12) was once abundant throughout the Atlantic coast of North America (COLLIGAN *et al.*, 1998). In the early 20th century, Virginia landed over half a million pounds for flesh and highly prized caviar for several consecutive years (HILDEBRAND and SCHROEDER, 1928). However, sturgeon populations were unable to support these high

Figure 12. Atlantic sturgeon (VIMS Fisheries Science Department Photo)

levels of exploitation. Their rapid growth, predictable seasonal migration patterns with distinct seasonal concentration areas (Bain, 1997), and unusual morphology (Boreman, 1997) made the species highly susceptible to capture. Late maturation and inconsistent spawning intervals combined to make the species biologically sensitive to overfishing (Boreman, 1997). Once the population was severely reduced, relatively small bycatch mortalities may have significantly hindered their reproductive potential, thus resulting in continued recruitment failure (Boreman, 1997). In addition to direct harvest, anthropogenic habitat alterations in the Chesapeake Bay watershed reduced the extent of, destroyed, or restricted access to many of the species' essential habitats. The Atlantic sturgeon depends on channel habitats for all life stages and on healthy freshwater habitats for reproduction; such biological needs are in direct conflict with human activities, such as dredging and dam construction, which alter habitats or reduce water quality (Secor *et al.*, 2000). Additional studies are necessary to identify the effects of these alterations and develop means of restoring essential habitats. The effectiveness of artificial spawning reefs has been demonstrated in other regions and such approaches could be evaluated for Chesapeake Bay tributaries. Stocking programs could be developed and pilot stocking studies may be used to evaluate habitat use.

The Atlantic sturgeon has been protected from harvest in Virginia since 1973, and along the coast by the Atlantic States Marine Fisheries Commission since 1998. A lack of stock recovery, however, has recently resulted in the recommendation by the NMFS Status Review Team to list the species by distinct population segments under the Endangered Species Act. These segments include the New York Bight, Chesapeake Bay, and Carolina populations of Atlantic sturgeon. In the York River system, potential spawning habitats are considered to be located above the upper limits of saltwater intrusion in the Mattaponi and Pamunkey rivers (Bushnoe *et al*., 2005). In the late 1960s to early 1970s, a single pound-net in the Pamunkey River was landing approximately 1000 lbs. of sturgeon per year. Today, we know that the Chesapeake Bay contains a genetically distinct stock and that reproduction occurs in the James River, however, geneticists do not agree as to whether the population in the York River is genetically unique (Wirgin, 2006), thus, there is no unequivocal evidence for reproduction in the York River watershed. Despite this, numerous juvenile Atlantic sturgeon have been collected at upriver sites since 2005, and a large group of juveniles were actively using soft-bottom habitats in and around beds of submerged aquatic vegetation at the mouth of the river in 2006. Interestingly, these young fish (presumably 2-3 years old) did not return to the York River in 2007. It is suspected that these fish may have left the Bay to start their coastal wandering pattern, a typical pattern for 2-3 year-old fish. Perhaps when these fish return in 8 to 10 years, the research needed to identify, preserve, and restore this magnificent fish's essential spawning and nursery habitats will have been completed.

The longnose gar (*Lepisosteus osseus*) (Figure 13) is part of an ancient family of fishes, Lepisosteidae, that has remained relatively unchanged for 100 million years. The longnose gar is a year-round resident in Virginia and is common in the upper York, Mattaponi, and Pamunkey rivers. This is the only species of gar found here. Longnose gar is considered a freshwater fish, but often inhabits oligohaline and mesohaline water and is occasionally captured at the mouth of the York River in salinities greater than 20 psu (Hildebrand and Schroeder, 1928, McGrath, unpublished). Scientific accounts of longnose gar in Virginia are sparse; those that exist mention only their presence, larval development, or individuals with abnormal coloration (Hildebrand and Schroeder, 1928, Pearson, 1942, Massman *et al.*, 1952, Mansuetti and Hardy, 1967, Woolcott and Kirk, 1976, Jenkins and Burkhead, 1993, Murdy *et al.*, 1997). The longnose gar spawns in the spring along the banks of the Mattaponi and Pamunkey rivers, with females releasing approximately 30,000 eggs. Juvenile longnose gar grow quickly, attaining 500 mm before the end of their first year. They have been reported to attain a maximum size of 1200 mm and live to 22 years of age (Netsch and Witt, 1962, Ferrara, 2001, McGrath, unpublished). The longnose gar is almost exclusively piscivorous in other riverine and lacustrine systems (Goodyear, 1967, Crumpton, 1970, Seidensticker, 1987, Tyler *et al.*, 1994). McGrath (unpublished) examined the stomach contents of 51 longnose gar from the York, Pamunkey, and Mattaponi rivers and found that the dominant prey items by weight and number were juvenile croaker (*Micropogonias undulatus*), menhaden (*Brevoortia tyrannus*), and spot (*Leistomus xanthurus*).

Figure 13. Longnose gar (Photo courtesy of Pat McGrath)

SHARKS, SKATES AND RAYS

Sharks, skates, and rays are seasonal visitors to the York River. These fish generally migrate from offshore waters or from south of Cape Hatteras and inhabit the bay between May and November. Most species prefer the higher salinity areas and beds of submerged aquatic vegetation in the lower bay and lower tributaries, such as the York River, but some are known to penetrate into fresh water.

Sharks

The family Carcharhinidae, or ground sharks, is represented in the York River system by the sandbar shark (*Carcharhinus plumbeus*; Figure 14) and the bull shark (*Carcharhinus leucas*). The sandbar shark is by far the most numerous shark found in the York River (Murdy *et al*.,1997; unpublished data,

Figure 14. Sandbar shark (Photo courtesy of Dean Grubbs)

VIMS Trawl Survey). Adult females use this area as a nursery for their young. Sandbar sharks as large as one meter in length have been taken in mesohaline waters. Primarily a bottom feeder, this shark is known to feed on crustaceans and its principal prey is soft adult female blue crabs. Although historically very common in the York River and the Chesapeake Bay, the abundance of sandbar sharks has declined in recent years (Figure 15). This shark has been the most valuable commercial shark species fished on the east coast since the late 1940s.

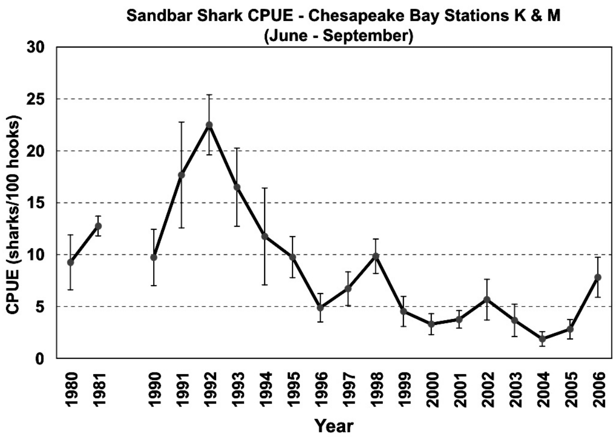

Figure 15. Sandbar shark CPUE (catch per unit effort) from two long-line stations in lower Chesapeake Bay (VIMS long-line survey).

Bull sharks are extremely rare in the York River (VIMS Trawl Survey, unpublished data). Bull sharks are one of the very few sharks known to penetrate into fresh water and have been captured as far as one thousand miles up river in the Mississippi River (Murdy *et al.*,1997). Bull sharks frequent the Chesapeake Bay and have been known to feed on sandbar shark pups. Adult bull sharks are extremely dangerous and are considered to be the second or third most likely shark to be implicated in attacks on humans. The numbers of bull sharks have been severely reduced due to commercial fishing (Murdy *et al.*,1997).

The smooth dogfish (*Mustelus canis*), a member of the family Triakidae (smoothhounds), is a frequent visitor to the York River. Smooth dogfish are a small, thin shark reaching a maximum size of 1.5 meters. Animals have been taken in the Chesapeake Bay as far north as the mouth of the Patuxent River, Maryland (Murdy *et al.*,1997). Smooth dogfish may be found in small schools and are active feeders on small invertebrates. They are often captured incidentally by anglers, haul seines, and pound nets and are also thought to survive short intervals in fresh water (Murdy *et al.*,1997, VIMS Trawl Survey, unpublished data).

Skates

Skates (family Rajidae) are distinguished from rays by not having a barbed tail. The clearnose skate (*Raja eglanteria;* Figure 16) is the most common skate in the bay; its name aptly describes the appearance of this species. The tail is covered with three rows of thorns. Clearnose skates are often taken by commercial and recreational fishers and are considered a nuisance. Like most skates and rays, this species feeds on bottom-dwelling organisms, taking mainly small invertebrates (Murdy *et al.*,1997).

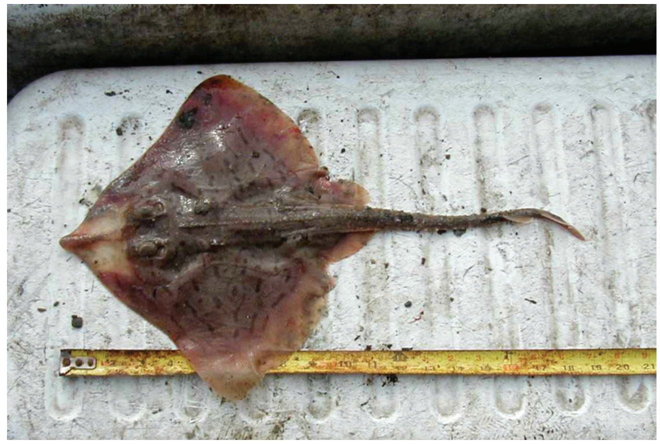

Figure 16. Clearnose skate (Photo courtesy of Virginia Tech University)

Rays

The smooth butterfly ray (*Gymnura micrura*; family Gymnuridae) lacks a tail barb and is, therefore, harmless. The shape of the body of this species resembles a butterfly and the skin is smooth without thorns. The disk width of this species can be as large as 1.2 m (Murdy *et al.*,1997, Smith and Merriner, 1978, VIMS Trawl Survey, unpublished data).

Members of the family Dasyatidae have diamond-shaped bodies with long slender tails (Smith and Merriner, 1978). The bluntnose stingray, *(Dasyatis say)* is gray to brown above and white underneath, and grows to a width of 1m. It is generally considered a nuisance species by commercial and recreational fishers. As with all members of the family, this species can deliver an extremely painful sting from the venom in the barbed tail.

The Atlantic stingray *(Dasyatis sabina)* is a small sting ray usually not exceeding 0.4 m in disk width, with an obviously triangular, pointed snout. It is rarely captured at depths greater than 3 m (Smith and Merriner, 1978). Atlantic stingrays are usually captured in mesohaline waters; they are rarely found north of the York River, which appears to be the northernmost extent of their range (Murdy *et al.*,1997, Smith and Merriner, 1978).

The southern stingray (*Dasyatis americana*; Figure 17) is a rare visitor to the lower York River. Original descriptions were made from an animal taken in Crisfield, Maryland (Hildebrand and Schroeder, 1928). The snout is barely projecting and the disk is wider than it is long, with a finlike fold along the underside of the tail (Murdy *et al.*, 1997). Disk width has been reported to reach 1.5 m (Smith and Merriner, 1978).

Figure 17. Southern stingray (Photo courtesy of Dean Grubbs)

Cownose rays (*Rhinoptera bonasus*; family Rhinopteridae), common visitors to the York

River, are strong swimmers that can cover long distances. A single school, estimated at 5 million adults and covering 1,100 acres, was observed in the 1980s in lower Chesapeake Bay (Murdy *et al*., 1997, Virginia Marine Resource Bulletin, 2007 Vol. 39, No 2.). These rays are often seen swimming in small schools on the surface, with the tips of both wings projecting from the surface of the water. Cownose rays may be identified by their somewhat pointed wings and two small lobes on the snout. Both adults and pups are found in the York River with adults captured as far upriver as Goff Point (river km 45). This species feeds on bivalves, including oysters and clams, and cownose rays are known to destroy portions of beds of submerged aquatic vegetation while feeding. Currently, efforts are underway to develop a commercial fishery, as this species is readily taken incidentally by pound nets (Figure 18). Cownose rays are slow to mature, reaching maturity at age eight, and producing few young (females have only one pup every year). Great care should be exercised in ensuring this species is not overfished.

Figure 18. Pound net fishers take a large haul of cownose rays. (Photo courtesy of Bob Fisher)

BLUE CRABS

The blue crab (*Callinectes sapidus*; Figure 19) is the most widely distributed species in the genus *Callinectes*, a genus of swimming crabs (Williams, 2007). Primarily because of the cold winters, the life history of the blue crab in Chesapeake Bay differs in some respects from its life history in lower latitudes (Hines, 2007). Crabs enter a state of low to no activity in the winter when temperatures drop below about 10 degrees Celsius, and they often bury in muddy sediments in deeper water during this period. Crabs quickly become active again when the water temperature rises. Males and females mate during the spring in the shallow areas of the Bay's tributary creeks and rivers, often in low salinity areas. Inseminated females migrate to the lower, more saline portions of the Bay to develop broods, or sponges (Figure 19). When the eggs hatch, larvae (zoeae) are transported into the open waters of the continental shelf. The larvae develop through seven or eight zoeal stages into postlarvae (megalopa), which rely on advective transport to return them to the Bay in the fall. Postlarvae typically settle in structured habitats, such as areas of submerged aquatic vegetation, where they metamorphose into juvenile crabs. Growth rates of blue crab in Chesapeake Bay are highly variable (Ju *et al.*, 2001), but some crabs can reach a size that makes them available to the commercial fishery within their first year of life (about 75 mm, or 3 inches).

Figure 19. Adult female blue crab (left panel) (Photo courtesy of Kristie Erickson). A female blue crab with a newly extruded egg mass or sponge (right panel).

Blue crabs are often a numerically dominant component of the benthic assemblage in shallow areas throughout the Bay, and are especially abundant in the York River. Areas of submerged aquatic vegetation are important as settlement and nursery habitats for juvenile crabs. Such structured habitats provide protection from predators during molting and a rich source of food. Near the mouth of the York River, aquatic vegetation beds around Goodwin and Allens Islands and the Guinea marshes routinely host large numbers of small and large crabs. Unstructured habitats, such as the muddy, detrital areas along marshes and the lower reaches of tidal creeks, are also important as foraging areas for juvenile and adult crabs. Within the York River, crabs range upstream to the tidal freshwater sections of the Mattaponi and Pamunkey rivers.

The blue crab is woven into the culture and economy of the Chesapeake Bay region more intimately than perhaps any other aquatic species (Warner, 1976). The blue crab has supported an important commercial fishery in the Bay since the late 1800s. Unfortunately, similar to other Bay resources, the blue crab population in the Bay has declined significantly from its historic abundance. Fishery-independent monitoring indicates that the population may be reduced to as little as 50% of the abundance observed in the early 1990s (CBSAC, 2007). As a result, watermen that depend on the blue crab for their livelihood have been negatively affected; recent commercial harvests have been the lowest on record since reporting began in 1945 (Figure 20; Miller *et al.*, 2005, CBSAC,

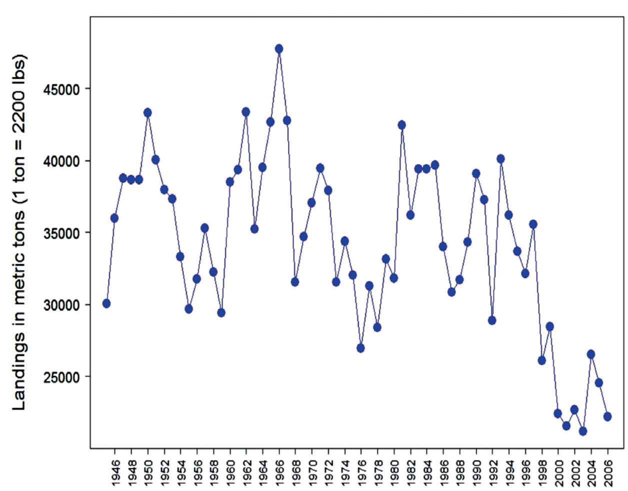

Figure 20. Chesapeake Bay commercial blue crab landings, 1945-2006 (Data from CBSAC 2007).

2007). Despite the decline, the blue crab fishery remains consistently one of the highest value fisheries in the Bay (NMFS, 2007), and is the leading contributor to the total U.S. landings of blue crab (Fogarty and Lipcius, 2007). The resilient nature of the blue crab's life history provides hope that the population can rebound, but management jurisdictions will need to define goals for the fishery and develop a more comprehensive management plan (CBSAC, 2007).

THREATS TO YORK RIVER FISHERIES

Threats to the fishes and fisheries of the York River system can be broadly categorized as habitat alteration and overfishing. Habitat alteration can take the form of water quality changes associated with increased levels of nutrients, sediments, and contaminants. Nutrient loading leads to algal blooms, which can decrease the concentration of dissolved oxygen (DO) in the water. Low DO can reduce the amount of suitable habitat for fish and can impair fish growth and reproduction. Air and water pollution can introduce harmful substances that affect the reproductive health of fishes. Changing the structure of the river by removing riparian (riverbank) habitat, eliminating vegetation, or dredging channels can change the amount and location of usable habitats for fishes. Structural changes to the York River system can affect the spawning habitats of anadromous species. Dams impede spawning migrations and water withdrawal facilities can pose a threat to the eggs and larvae of species that spawn in freshwater. Overharvesting leads to low number of reproductively viable adults, and consequently, fewer young are produced.

ONGOING AND FUTURE RESEARCH

The Virginia Institute of Marine Science has several programs to assess the relative abundance of fish species at the juvenile stage. The VIMS Juvenile Fish Survey collects monthly samples in the York River system, including three stations in the Pamunkey River. Data from the survey are used to develop abundance indices for several species, including Atlantic croaker and summer flounder. The VIMS Juvenile Striped Bass Seine Survey targets young-of-the-year striped bass and samples in the York system from Clay Bank to river km 96 in the Mattaponi River and river km 112 in the Pamunkey River. This survey also generates an index for juvenile American shad. Adult American shad abundance is monitored in the York River by VIMS researchers each spring. The abundance of juvenile American eels is monitored each spring in two creeks in the lower York River.

Using fish collected by these surveys, food web interactions are examined by the Chesapeake Bay Trophic Interactions Laboratory Services (CTILS) group at VIMS. These data are used to monitor changes in fish diets over time and location, as well as to model trophic linkages among species.

Acoustic tagging—attaching or implanting tags in fish that emit sonic "pings" —has been used to investigate fish behavior and movements (Figure 21) and VIMS researchers are studying summer flounder movements in the lower York River using this technology. The behavior of American shad has also been examined using acoustic telemetry. Additionally, the movements of striped bass and white perch have been examined in the Poropotank River (a York River tributary).

Ensuring the continued health of the York River system's fisheries will require continued monitoring and assessment of juvenile fish abundance, spawning stock abundance, and understanding of trophic linkages. Studies on movement and habitat use are pivotal to understanding and delineating habitats that are essential for fish survival and reproduction. Periodic research on ichthyoplankton (fish eggs and larvae) may be necessary to determine the potential effects of land use changes in the watershed.

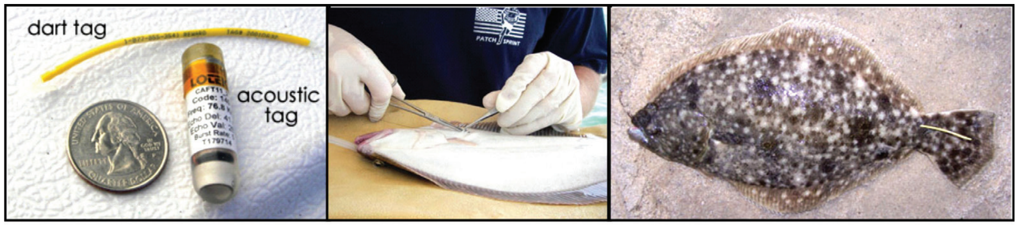

Figure 21. Acoustic and dart tags used for summer flounder and shad tracking research at VIMS (left panel). Surgically implanting summer flounder with an acoustic transmitter (middle panel). Summer flounder with an implanted acoustic transmitter and an external tag (right panel) (Photos courtesy of VIMS Department of Fisheries Science)

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Amphibians, Reptiles, Birds and Mammals of the York River

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ABSTRACT

The York River and its watershed support many natural vegetative communities, from aquatic grass beds to tidal marshes to a variety of woodlands. These communities support a wide variety of resident and migratory amphibians, reptiles, birds and mammals. There are eight families and 26 species of amphibians and ten families and 36 species of reptiles represented within the York River watershed. All three species of sea turtles are protected under the Endangered Species Act and the Northern diamond-backed terrapin is a species of concern. Approximately 230 bird species, resident and migratory, have been recorded within the Chesapeake Bay area. Over 50 families and 190 species of birds have been observed along the estuarine environments of the York River. Specific Reserve components support Bald Eagle nests and Great Blue Heron rookeries. Nineteen families and 50 species of mammals are represented within the York River and its watershed. Of special note is the infrequent occurrence of large marine mammals, such as the bottlenose dolphin and manatee, within the lower York River region.

INTRODUCTION

From its headwaters in the Mattaponi and Pamunkey Rivers to its entrance into the Chesapeake Bay, the York River provides a variety of riverine and estuarine habitats. Consequently the York River system supports a diverse array of vertebrates. Portions of the Chesapeake Bay National Estuarine Research Reserve in Virginia located along the York River provide opportunities for study and observation of many of these species.

The watershed of the York River supports many natural communities, including tidal freshwater marshes, tidal oligohaline marshes, tidal mesohaline and polyhaline marshes, tidal shrub swamps, tidal bald cypress forests and woodlands, tidal hardwood swamps, tidal freshwater and oligohaline aquatic beds and tidal mesohaline and polyhaline aquatic beds (http://www.dcr.virginia.gov/natural_heritage/ncestuarine.shtml). These multiple natural vegetative communities, in turn, support a wide variety of resident and migratory birds, as well as many reptiles, amphibians, and mammals which are primarily year-round residents.

AMPHIBIANS

Amphibians within the York River watershed are dependent upon freshwater and limited by salt intrusion. All species are therefore located primarily in the upper portions of the river's tributaries or at its headwaters. Eight families and approximately 26 species of amphibians are represented in the York watershed, including species such as: marbled salamander (*Ambystoma opacum*; Figure 1), Eastern red-spotted newt *(Notophthalmus viridescens)*, American toad *(Bufo americanus)*, pine woods treefrog *(Hyla femoralis)*, and bullfrog *(Rana catesbeiana)*. The Appendix provides a listing of documented species.

Figure 1. Marbled salamander (Photo courtesy of the Virginia Fish and Wildlife Information Service)

REPTILES

Ten families and 36 species of reptiles occur along the York River and its tributaries, including 11 species of turtle, six species of lizards and 19 species of snakes. Of the four species of turtles found in brackish or salty portions of the river, three are sea turtles (commonly found near the mouth of the York River), the fourth is the Northern diamond-backed terrapin (*Malaclemmys terrapin*; Figure 2). This turtle is common along most portions of the lower river and its brackish tributaries where typical food items (fiddler crabs and periwinkle snails) are in abundance. Terrapins prefer open, sandy habitat for breeding where they lay eggs in sandy soils above the high tide line. Two species of sea turtles that are regular visitors to the saltier portions of the river (Mansfield, 2006), are the loggerhead turtle (*Caretta caretta*; Figure 3) and Kemp's Ridley *(Lepidochelys kempii)*. The green sea turtle *(Chelonia mydas)* is relatively rare. All species of sea turtles found within the

Figure 2. Northern Diamond-backed Terrapin (Photo courtesy of the Virginia Fish and Wildlife Information Service)

Figure 3. Loggerhead Turtle (Photo courtesy of James Cook University)

US are federally protected under the Endangered Species Act (ESA). The lower Chesapeake Bay is an important developmental area for both juvenile loggerheads and Kemp's Ridleys as they move into the lower bay and York River for foraging and shelter. Between 5,000 and 10,000 sea turtles enter the Chesapeake Bay each spring and summer, and Mansfield (2006) estimates approximately 1,000 to 3,000 individuals are seasonal residents in the lower Bay. The majority are either juvenile loggerheads or Kemp's Ridleys that use the Bay as a feeding ground. Mansfield (2006) found that juvenile loggerheads and Kemp's Ridleys sea turtles spend approximately 10% of their time at the surface. Unfortunately, it is at this time that they are subject to injury and death due to encounters with vessels and humans. In the 1980s approximately 33% of Virginia's sea turtle mortalities were attributed to entanglement in large mesh pound net leaders (Mansfield, 2006). Winter temperatures in Virginia are too cold for the turtles to remain year round, and many individuals found in the lower bay are migrating along the East Coast of the US, or are dispersing young. Since 1979, VIMS has served as the Commonwealth of Virginia's center for the monitoring, study and conservation of endangered and threatened sea turtles within Virginia's waters. Approximately 250 to 350 sea turtles strand within Virginia's waters each year. Most strand during May and June when populations enter the bay, and in October when leaving. Sick or injured sea turtles are treated and/or rehabilitated at the VIMS campus or other nearby rehabilitation facilities before release back into the wild.

Two families, and 20 species of snakes are known from the York River watershed. One of the most common species may be the northern water snake (*Nerodia sipedon*; Figure 4), which is frequently mistaken for the Eastern cottonmouth (*Agkistrodon piscivorous*; Figure 5). The cottonmouth is one of only two venomous snakes found in the watershed, the other being the Northern copperhead *(Agkistrodon contortrix)*. A listing of reptile species documented from the York River watershed is provided in the Appendix.

Figure 4. Northern Water Snake (Photo courtesy of the University of North Carolina)

Figure 5. Eastern Cottonmouth (Photo courtesy of the Armed Forces Pest Management Board)

BIRDS

Approximately 230 bird species have been recorded from the Chesapeake Bay area, both residents and migrants. In marsh, swamp, beach and more open estuarine environments along the York River, approximately 52 families and 192 species are represented. Most species are allied with swamps and associated woodlands, and with fresh and saltwater marshes. A listing of bird species documented from the York River and its tributaries is provided in the Appendix.

Extensive low marsh areas support significant populations of Clapper Rail *(Rallus longirostris)*, Seaside Sparrow *(Ammodramus maritimus)*, and Marsh Wrens *(Cistothorus palustris)*, while tide pools support a large diversity of breeding species, as well as, migratory species. Large high marsh areas provide habitat for breeding populations of Sedge Wrens *(Cistothorus platensis)*, Northern Harriers (*Circus cyaneus*; Figure 6), Prairie Warblers

Figure 6. Northern Harrier (Photo courtesy of Coffee Creek Watershed Preserve)

Figure 7. American Oystercatcher (Photo courtesy of Daphne Bremer)

(Dendroica discolor), and Eastern Meadowlarks *(Sturnella maffna)*. Least Terns *(Sternula antillarum)* and American Oystercatchers *(Haematopus palliates)* are found on sandy berms and barriers while scattered pine hummocks and adjacent maritime forests support significant populations of Brown-headed Nuthatches *(Sitta pusilla)* and Chuck-wills-widows *(Caprimulgus carolinensis)*. Marsh, scrub and overwash habitats at the isolated marsh islands of Goodwin Islands support numerous breeding birds including the American Black Ducks *(Anas rubripes)* and American Oystercatchers (*Haemoatopus palliates*; Figure 7) (VAD-CR 2005a). American Oystercatchers are on the Audubon Watchlist and are listed as a high priority species in the U.S. Shorebird Conservation Plan.

Aerial surveys of Bald Eagle *(Haliaeetus leucocephalus)* nests and heron nest colonies are flown annually by staff of the Center for Conservation Biology of the College of William and Mary (http://ccb.wm.edu). Historically, Goodwin Islands supported a large nesting colony of Great Blue Herons *(Ardea herodias)*. By the late 1980s, the colony on Goodwin Islands had grown to approximately 150 pairs and had begun to split and develop other nesting colonies elsewhere. The Catlett Islands reserve site currently supports a small nesting colony of Great Blue Herons (Erdle and Heffernan, 2005b). Until a hurricane in the fall of 2003 destroyed the nest and large nest trees, at least one pair of Bald Eagles nested at Goodwin Islands, as well as at Catlett Islands. Unlike the Goodwin Islands reserve site, large nest trees are still intact at Catlett Islands, so re-nesting there is possible. Both nesting herons and Bald Eagles are sensitive to disturbance, therefore the isolated locations of these two reserve sites provide critical habitat for nest development. Currently, one Bald Eagle nest is known near the Taskinas Creek Reserve site (Myers *et al.*, 2008).

Unlike the herons and Bald Eagles, Osprey *(Pandion haliaetus)* are widespread nesters in this region and appear to be more toleratant of disturbance. There are over 2,000 breeding pairs in the Chesapeake Bay area; the largest known concentration in the world (www.fws.gov/chesapeakebay/osprey.htm). Osprey nesting is common adjacent to reserve monitoring sites along the York River system (Figure 8) and the population appears to be increasing.

Figure 8. Osprey and chicks on nest near CBNERRSVA York River water quality monitoring station (Photo courtesy of Betty Neikirk, VIMS)

Threats to bird populations within the site in general and the Goodwin Islands region, in particular, include: 1) loss of habitat to the invasive marsh grass-common reed *(Phragmites australis)*, 2) loss of habitat to sea-level rise, 3) increases in mammal populations and associated predation, and 4) human disturbance. The aggressive invasive plant, common reed, is spreading throughout Goodwin Islands and many other areas in the York River area. Although some high marshes within this system have not been degraded to the same extent as many areas within the upper Chesapeake Bay, many marshes within the system are highly threatened. Rising sea levels continue to threaten low-lying areas, and isolated marsh islands are particularly vulnerable to this ongoing process. Over the past 30 years, mammalian predators such as raccoon, fox, domestic dog and cat have had a detrimental effect on reproductive rates of marsh-bird populations. Human disturbance is a chronic problem at most locations. It is notable that at the present time Bald Eagle, Osprey and Peregrine Falcons *(Falco peregrinus)* have made substantial recoveries from near extirpation in this region.

MAMMALS

Approximately 19 families and 50 species of mammals are represented within the York River watershed. A listing of species documented from the York River watershed is provided in the Appendix. Most of these are small to medium-sized mammals, as there are few large mammals remaining in the area, although some large marine mammals do occur here. Some species, like muskrat *(Ondatra zibethicus)*, raccoon *(Procyon lotor)*, beaver *(Castor canadensis)*, river otter *(Lutra canadensis)*, and white-tailed deer *(Odocoileus virginianus)* are relatively common, while bobcats *(Lynx rufus)* and black bear *(Ursus americanus)* are uncommon. There are few significant invasive mammal species in this area, although the potential for establishment of the nutria *(Myocastor coypus)* in the York system is high (Chesapeake Bay Nutria Working Group 2003). The white-tailed deer (a native species) can have significant negative effects on native tree and herbaceous plant regeneration, recruitment and compositions (Horsely *et al.*, 2003) and can even disrupt bird populations (deCaleta, 1994). Deer avoid browsing on some invasive non-native plants, such as Japanese stilt grass (Tu, 2000) and therefore can indirectly increase the spread of these invasives. Deer were nearly hunted out of many areas in Virginia by the end of the 19th century, however factors such as the implementation of hunting laws, loss of natural predators and increases in foraging habitats has resulted in increased populations that in many areas may now exceed estimated pre-settlement deer densities (Erdle and Heffernan, 2005a). Although deer are currently in abundance overall, many mammal populations are threatened by large-scale landscape alterations and habitat fragmentation. These trends are occurring in the York River watershed, as they are everywhere. Therefore, large, unfragmented riverine forests and marshes of the reserve, as well as adjacent and nearby lands serve as critical refugia for mammals in a landscape that is increasingly altered and developed.

Large marine mammals are infrequent visitors in the York system, and generally occur close to the Chesapeake Bay and in the lowest reaches of the river. The most common marine mammal, the bottlenose dolphin (*Tursiops truncates*; Figure 9), is an occasional to frequent visitor in summer months (Blaylock, 1988). Most bottlenose dolphin are found near shore with water depths of less that 10m. It is thought that pod density is related to prey abundance with the main prey in this area being Atlantic croaker *(Micropogon undulates)*, spot *(Leiostomus xanthurus)*, and sea trout (*Cynoscion* sp.). Mean pod size is greatest in May and September during peak periods of migration (Blaylock, 1988). Another marine mammal occasionally documented from the York River is the manatee *(Trichechus manatus)* (Morgan *et al.*, 2002). Usually manatee occurrences consist of single individuals that have traveled 800 or more miles north of its usual habitat in Florida. Occasionally these individuals succumb to cold stress in the fall and are found dead. In 1994 though, a manatee nicknamed "Chessie" was observed to have traveled up the Eastern Seaboard into the Chesapeake Bay. As water temperatures dropped, the animal was captured and released back in Florida. In 1995 that same individual again migrated north and was observed in Rhode Island, and in 2001 that same individual was again observed in Virginia. Some migration patterns and/or movements by individuals are not well understood at this time.

Figure 9. Bottlenose dolphin common to the York River (Photo courtesy of Wikimedia Commons)

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APPENDIX

COMMON AMPHIBIANS, REPTILES, BIRDS AND MAMMALS OF YORK RIVER SYSTEM

AMPHIBIANS

Family Ambystomatidae-Mole salamanders
- *Ambystoma maculatum*-spotted salamander
- *Ambystoma opacum*-marbled salamander
- *Ambystoma mabeei*-Mabee's salamander

Family Salamandridae-Newts
- *Notophthalmus viridescens*-Eastern red-spotted newt

Family Plethodontidae-Lungless salamanders

REPTILES

Family Chelydridae-Snapping turtles
- *Chelydra serpentine*-snapping turtle

Family Kinosternidae-Musk and mud turtles
- *Sternotherus odoratus*-stinkpot
- *Kinosternon subrubrum*-Eastern mud turtle

Family Emydidae-Box and water turtles
- *Clemmys guttata*-spotted turtle
- *Terrapene carolina carolina*-Eastern box turtle
- *Malaclemmys terrapin terrapin*-Northern diamondback terrapin
- *Chrysemys rubriventris rubriventris*-Northern red-bellied turtle
- *Chrysemys picta picta*-Eastern painted turtle

Family Cheloniidae-Sea turtles
- *Chelonia mydas mydas*-Atlantic green turtle
- *Caretta caretta*-Loggerhead turtle
- *Lepidochelys kempii*-Kemp's Ridley sea turtle

Family Iguanidae-Iguanid lizards
- *Sceloporus undulates*-fence lizard

Family Teiidae-Whiptail lizards
- *Cnemidophorus sexlineatus sexlineatus*-six-lined racerunner

Family Scincidae-Skinks
- *Scincella lateralis*-ground skink
- *Eumeces fasciatus*-five-lined skink
- *Eumeces laticeps*-broad-headed skink

Family Anguidae-Glass lizards
- *Ophisaurus attenuatus*-Eastern slender glass lizard

Family Colubridae-Colubrid snakes
- *Nerodia sipedon sipedon*-Northern water snake
- *Storeria dekayi dekayi*-Northern brown snake
- *Thamnophis sirtalis sirtalis*-Eastern garter snake
- *Thamnophis sauritus sauritus*-Eastern ribbon snake
- *Virginia valeriae*-smooth earth snake
- *Virginia striatula*-rough earth snake
- *Heterodon platyrhinos*-Eastern hognose snake
- *Diadophis punctatus edwardsi*-Northern ringneck snake
- *Carphophis amoenus amoenus*-Eastern worm snake
- *Farancia erytrogramma*-rainbow snake
- *Coluber constrictor constrictor*-Northern black racer
- *Opheodrys aestivus*-rough green snake
- *Elaphe guttata guttata*-corn snake
- *Elaphe obsoleta obsolete*-black rat snake
- *Lampropeltis getulus getulus*-Eastern kingsnake
- *Lampropeltis triangulum triangulum*-Eastern milk snake
- *Lampropeltis calligaster rhombomaculata*-mole snake
- *Cemophora coccinea*-scarlet snake

Family Viperidae-Vipers and pit-vipers
- *Agkistrodon contortrix mokeson*-Northern copperhead
- *Agkistrodon piscivorous*-Eastern cottonmouth

MAMMALS

Family Didelphidae-Opossums
- *Didelphis virginiana*-Virginia opossum

Family Soricidae-Shrews
- *Sorex longirostris longirostris*-Southeastern shrew
- *Cryptotis parva*-least shrew
- *Blarina carolinensis*-Southern short-tailed shrew
- *Blarina brevicauda*-Northern short-tailed shrew
- *Sorex hoyi*-pygmy shrew

Family Talpidae-Moles
- *Scalopus aquaticus*-Eastern mole
- *Condylura cristata*-star-nosed mole

Family Vespertilionidae-Vespertilionid bats
- *Myotis lucifugus*-little brown myotis
- *Lasionycteris noctivagans*-silver-haired bat
- *Pipistrellus subflavus*-Eastern pipistrelle
- *Eptesicus fuscus*-big brown bat
- *Nycticeius humeralis*-evening bat
- *Lasiurus borealis*-Eastern red bat
- *Lasiurus intermedius floridanus*-Northern yellow bat

Family Leporidae-Hares and rabbits
- *Sylvilagus palustris*-marsh rabbit
- *Sylvilagus floridanus*-Eastern cottontail

Family Sciuridae-Squirrels
- *Marmota monax*-woodchuck
- *Tamias striatus*-Eastern chipmunk
- *Sciurus carolinensis*-gray squirrel
- *Glaucomys volans*-Southern flying squirrel

Family Castoridae-Beavers
- *Castor canadensis*-American beaver

Family Muridae-Murid rats and mice
- *Reithrodontomys humulis*-Eastern harvest mouse
- *Peromyscus leucopus*-white-footed mouse
- *Peromyscus gossypinus*-cotton mouse
- *Ochrotomys nuttalli*-golden mouse
- *Oryzomys palustris*-marsh rice rat
- *Sigmodon hispidus*-hispid cotton rat
- *Clethrionomys gapperi*-Southern red-backed vole
- *Microtus pennsylvanicus*-meadow vole
- *Microtus pinetorum*-woodland vole
- *Ondatra zibethicus*-common muskrat
- *Rattus norvegicus*-Norway rat (introduced)
- *Mus musculus*-house mouse (introduced)

Family Zapodidae-Jumping mice
- *Zapus hudsonius hudsonius*-meadow jumping mouse

Family Myocastoridae-Nutria
- *Myocastor coypus*-nutria (introduced)

Family Delphinidae-Dolphins
- *Tursiops truncates*-bottle-nosed dolphin

Family Cervidae-Deer
- *Odocoileus virginianus*-white-tailed deer

Family Canidae-Dogs

Vulpes vulpes fulva-red fox

Urocyon cinereoargenteus-gray fox

Canis latrans-coyote

Family Ursidae-Bears

Ursus americanus americanus-black bear

Family Procyonidae-Raccoons and weasels

Procyon lotor-raccoon

Mustela frenata-long-tailed weasel

Mustela vison-mink

Lutra canadensis-Northern river otter

Family Mephitidae-Skunks

Mephitis mephitis-striped skunk

Family Felidae-Cats

Lynx rufus-bobcat

Family Phocidae-Hair seals

Phoca vitulina-harbor seal

Family Trichechidae-Manatees

Trichechus manatus-manatee

BIRDS

Gavia immer	Common Loon
Podiceps grisegena	Red-Necked Grebe
Podiceps auritus	Horned Grebe
Podilymbus podiceps	Pied-Billed Grebe
Pelecanus occidentalis	Brown Pelican
Morus bassanus	Gannet
Phalacrocorax auritus	Double-Crested Cormorant
Botaurus lentiginosus	American Bittern
Ixobrychus exilis	Least Bittern
Nycticorax nycticorax	Black-Crowned Night Heron
Nyctanassa violacea	Yellow-Crowned Night Heron
Butorides virescens	Green Heron
Bubulcus ibis	Cattle Egret
Egretta caerulea	Little blue Heron
Egretta rufescens	Reddish Egret
Egretta tricolor	Louisiana Heron
Egretta thula	Snowy Egret
Ardea alba	Common Egret
Ardea herodias	Great Blue Heron
Plegadis falcinellus	Glossy Ibis
Cygnus olor	Mute Swan
Olor columbianus	Whistling Swan
Chen caerulescens	Snow Goose
Branta canadensis	Canada Goose
Branta bernicla	Brant
Aix sponsa	Wood Duck
Anas americana	American Widgeon
Anas strepera	Gadwall
Anas crecca	Common Teal
Anas carolinensis	Green-Winged Teal
Anas platyrhynchos	Mallard
Anas rubripes	Black Duck
Anas acuta	Northern Pintail
Anas discors	Blue-Winged Teal
Anas cyanoptera	Cinnamon Teal
Anas clypeata	Shoveler
Aythya valisineria	Canvasback
Aythya americana	Redhead
Aythya collaris	Ring-Necked Duck
Aythya marila	Greater Scaup
Aythya affinis	Lesser Scaup
Somateria mollissima	Common Eider
Clangula hyemalis	Oldsquaw
Melanitta nigra	Common Scoter
Melanitta perspicillata	Surf Scoter
Bucephala albeola	Bufflehead
Bucephala clangula	Common Goldeneye
Lophodytes cucullatus	Hooded Merganser
Mergus serrator	Red-breasted Merganser
Mergus merganser	Common Merganser
Oxyura jamaicensis	Ruddy Duck
Buteo lagopus	Rough-Legged Hawk
Haliaeetus leucocephalus	Bald Eagle
Circus cyaneus	Marsh Hawk
Pandion haliaetus	Osprey
Falco peregrinus	Peregrine Falcon
Rallus longirostris	Clapper Rail
Rallus elegans	King Rail
Rallus limicola	Virginia Rail
Porzana carolina	Sora
Gallinula chloropus	Common Gallinule
Fulica americana	American Coot
Haematopus palliatus	American Oystercatcher
Charadrius vociferus	Killdeer
Pluvialis dominica	American Golden Plover
Pluvialis squatarola	Black-Bellied Plover
Scolopax minor	American Woodcock
Gallinago gallinago	Common Snipe
Catoptrophorus semipalmatus	Willet
Actitis macularia	Spotted Sandpiper
Tringa melanoleuca	Greater Yellowlegs
Tringa flavipes	Lesser Yellowlegs
Erolia alpina	Dunlin
Larus atricilla	Laughing Gull
Larus delawarensis	Ring-Billed Gull
Larus hyperboreus	Glaucous Gull
Larus fuscus	Lesser Black-Backed Gull
Larus argentatus	Herring Gull
Larus marinus	Great Black-Backed Gull
Rhynchops niger	Black Skimmer
Sterna maxima	Royal Tern
Sterna caspia	Caspian Tern
Sterna hirundo	Common Tern
Sterna antillarum	Least Tern
Tyto alba	Barn Owl
Strix varia	Barred Owl
Bubo virginianus	Great-Horned Owl
Archilochus colubris	Ruby-Throated Hummingbird
Megaceryle alcyon	Belted Kingfisher
Dryocopus pileatus	Pileated Woodpecker
Melanerpes carolinus	Red-Bellied Woodpecker
Picoides pubescens	Downy Woodpecker
Picoides villosus	Hairy Woodpecker
Sphyrapicus varius	Easter Sapsucker
Colaptes auratus	Yellow-Shafted Flicker
Gallinula chloropus	Common Gallinule
Sayornis phoebe	Easter Phoebe
Tachycineta bicolor	Tree Swallow
Riparia riparia	Bank Swallow
Hirundo rustica	Barn Swallow
Corvus ossifragus	Fish Crow
Corvus brachyrhynchos	Common Crow
Sitta carolinensis	White-Breasted Nuthatch

Sitta pusilla	Brown-Headed Nuthatch
Troglodytes troglodytes	Winter Wren
Cistothorus palustris	Long-Billed Marsh Wren
Cistothorus platensis	Short-Billed Marsh Wren
Dumetella carolinensis	Catbird
Polioptila caerulea	Blue-Gray Gnatcatcher
Vireo griseus	White-Eyed Vireo
Mniotilta varia	Black and White Warbler
Vermivora pinus	Blue-Winged Warbler
Dendroica dominica	Yellow-Throated Warbler
Dendroica discolor	Prairie Warbler
Dendroica coronata	Myrtle Warbler
Setophaga ruticilla	American Redstart
Limnothlypis swainsonii	Swainson's Warbler
Protonotaria citrea	Prothonotary Warbler
Geothlypis trichas	Yellowthroat
Wilsonia citrina	Hooded Warbler
Dolichonyx oryzivorus	Bobolink
Sturnella magna	Eastern Meadowlark
Agelaius phoeniceus	Red-Winged Blackbird
Quiscalus major	Boat-Tailed Grackle
Molothrus ater	Cowbird
Carduelis tristis	American Goldfinch
Ammodramus maritimus	Seaside Sparrow
Melospiza melodia	Song Sparrow
Zonotrichia albicollis	White-Throated Sparrow
Carpodacus mexicanus	House Finch
Sayornis phoebe	Easter Phoebe

CBNERRVA Research and Monitoring Program

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ABSTRACT

The overall goal of the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) research and monitoring program is to promote, coordinate and conduct research and monitoring to enhance the scientific understanding and management of the York River and southern Chesapeake Bay coastal ecosystems. The regions of greatest scientific emphasis are located within four Reserve sites located along the York-Pamunkey River estuarine system. Primary research and environmental monitoring areas include: estuarine and shallow water environments including benthic communities, submerged aquatic vegetation and emergent wetlands habitats, open water regions and adjacent watersheds and air sheds. Both national priority (NOAA) and Chesapeake Bay specific (Chesapeake Bay Program) research focus areas are pursued within the Research Reserve with goals to: enhance scientific understanding of coastal ecosystems, surrounding environments and the natural and human processes influencing such systems; and, promote the effective management and conservation of natural and cultural coastal resources through informed decision-making. A System-wide Monitoring Program (SWMP) initiated by the Estuarine Reserves Division (ERD) of NOAA provides standardized data on national estuarine environmental trends through similar measurements of abiotic and biotic variables as well as watershed and land use classifications and measurements at each of the 27 Reserves. Data are compiled electronically at a central data management location and are available via web interface (www.vecos.org). Ongoing York River monitoring programs at the CBNERRVA reserve sites include; meteorological and streamflow monitoring, water quality monitoring and biological monitoring are available through the Reserve or via web interface. Multi-parameter water quality, in situ monitors at both fixed and buoyed stations, point sampling and continuous underway flow-through monitoring form the basis of the water quality monitoring program. Research opportunities at Reserve sites are available to any qualified scientist, academician or student affiliated with a university, college or school, non-profit organizations, and non-academic research institutions. In addition, the Reserve sponsors competitive graduate research fellowships through the NERRS Graduate Research Fellowship (GRF) Program for student research in the York River system.

GENERAL APPROACH

The overall goal of the CBNERRVA Research and Monitoring Program is to promote, support, coordinate, and engage in research and monitoring efforts that enhance scientific understanding of estuarine and watershed ecosystems and associated processes and functions, and to communicate results of research to assist in environmental education and wise stewardship of coastal resources. Enhancing scientific understanding of the York River and southern Chesapeake Bay coastal ecosystems, surrounding environments and the natural and human processes influencing systems requires a broad range of expertise and capabilities. In order to contribute to this increased understanding, the Reserve pursues a variety of approaches including:

- Encouraging, and where possible supporting, research and monitoring by individual investigators or groups with emphasis given to those addressing Reserve priorities;
- Collaborating with individual investigators or groups conducting research and related monitoring within the York River and Bay region;
- Developing in-house research and monitoring programs led by CBNERRVA associated faculty and senior staff; and
- Collecting, synthesizing and publishing/disseminating available information.

The region of scientific emphasis is focused within the four Reserve components, it also extends beyond Reserve boundaries to include the entire York River system, which includes the Pamunkey and Mattaponi Rivers, its watershed, and water regions that affect or are affected by the York River system. Extending beyond Reserve component boundaries is necessary to address large-scale processes that influence the York River system and allows for collaborative efforts with other individuals or entities responsible for complimenting research and monitoring programs. This collaborative effort results in more integrated and comprehensive research and monitoring programs for the Reserve and other Bay-wide groups.

There are typically 30 or more research and monitoring oriented projects conducted on an annual basis by researchers from a variety of state and federal agencies, academic institutions, and private consulting firms within Reserve boundaries. Primary research and environmental monitoring focus areas conducted by CBNERRVA scientists include:

- Ecology and management aspects of estuarine and coastal shallow water environments, with an emphasis on benthic communities including submerged aquatic vegetation, and emergent marshes, water column processes and physical conditions (e.g. waves, currents and water depth);

- Watershed and airshed material flux into coastal waters;
- Ecological impacts of large-scale episodic events, long-term climatic changes and sea-level rise; and
- Participation in the development and implementation of local (Virginia Estuarine and Coastal Observing System), Bay-wide (Chesapeake Bay Observing System), and regional (Mid-Atlantic Coastal and Ocean Observing Regional Association) observing systems.

NATIONAL PRIORITY RESEARCH FOCUS AREAS

NOAA has recently redesigned its approach to research by moving towards a more interdisciplinary, cross-cutting strategy to address identified priority research areas (NOAA 2005). The new infrastructure for NOAA's research focuses on four broad mission goals: (1) Ecosystems, (2) Climate, (3) Weather and Water, and (4) Commerce and Transportation. NERRS is a primary contributing member of the Coastal and Marine Resources Program within the Ecosystems Goal Team. The mission of the Ecosystems Goal is to protect, restore and manage the use of coastal and ocean resources through an ecosystem approach to management. Additionally, NERRS also contributes to the Climate Goal and Weather and Water Goal. NERRS has identified the following five priority research areas to complement the funding priorities outlined above:

- Habitat and ecosystem processes;
- Anthropogenic influences on estuaries;
- Habitat conservation and restoration;
- Species management; and
- Social science and economics.

Currently, there are two reserve system-wide efforts to fund priority estuarine research. The Graduate Research Fellowship Program (GRF) supports students to produce high quality research which addresses relevant focus areas in the reserves. Secondly, research is funded through the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), which will transition into the National Coastal and Estuarine Research and Technology (NCERT) Program, which supports development and application of tools to enhance understanding and management of coastal ecosystems.

CHESAPEAKE BAY RESEARCH FOCUS AREAS

In addition to the national funding and programmatic priorities, NOAA recognizes that individual reserves develop, support, and implement site-specific research programs to address local and regional research and management needs. In 1983, Virginia, Maryland, Pennsylvania, the District of Columbia, the USEPA and the Chesapeake Bay Commission formally agreed to coordinate interstate planning and programs for the Chesapeake Bay and its tributaries and establish mechanisms to facilitate that coordination. Since 1983, this joint commitment has led to new levels of government cooperation, including a more comprehensive Chesapeake Bay Agreement by the Chesapeake Executive Council in 1987, which accelerated advances in the Bay's restoration and protection. To address data and information gaps, the Chesapeake Executive Council developed a Comprehensive Research Plan for the Chesapeake Bay (Chesapeake Executive Council, 1988).

In June 2000, Chesapeake Bay Program partners adopted the Chesapeake 2000 Agreement, a strategic plan to achieve a vision for the future of the Chesapeake Bay (Chesapeake Bay Program, 2000). A vision that includes abundant, diverse populations of living resources, fed by healthy streams and rivers, sustaining strong local and regional economies, and our unique quality of life. Chesapeake 2000 is one of the most aggressive and comprehensive watershed restoration plans ever developed. The agreement is the result of a comprehensive three-year stakeholder-driven process involving more than 300 scientists, resource managers, policymakers and citizens from all parts of the Bay watershed. Restoration of an ecosystem as complex as the Chesapeake Bay requires work on many fronts. The agreement details nearly one hundred commitments important to Bay restoration, organized into five strategic focus areas:

- Protecting and Restoring Living Resources - Chesapeake 2000 aims to restore, enhance and protect the finfish, shellfish and other living resources, their habitats and ecological relationships to sustain all fisheries and provide for a balanced ecosystem.
- Protecting and Restoring Vital Habitats - The Bay Program aims to preserve, protect and restore those habitats and natural areas that are vital to the survival and diversity of the living resources of the Bay and its rivers.
- Improving Water Quality - Improving water quality in the Bay and its rivers is the most critical element in ensuring the future health of Chesapeake Bay.
- Managing Lands Soundly - Because pollutants on land are easily washed into streams and rivers, our actions on land ultimately affect the Bay.
- Engaging Individuals and Local Communities - To contribute to Bay restoration, we have to first be concerned about resource stewardship in our own communities, homes and backyards.

RELEVANT CBNERRVA GOALS, OBJECTIVES AND STRATEGIES

CBNERRVA strives to achieve NERRS and VIMS research oriented goals by implementing a variety of strategies in support of CBNERRVA programmatic goals and objectives listed below. (Reay *et al*., 2008)

<u>Goal 1. Enhance scientific understanding of coastal ecosystems, surrounding environments and the natural and human processes influencing such systems.</u>

Objective 1. Characterize and monitor coastal ecosystems and surrounding environments to describe reference conditions and quantify spatial and temporal changes.

Strategies:

- Maintain and enhance long-term water quality monitoring in the York River and other appropriate water bodies to allow criteria and standards development, and overall water quality condition assessments.
- Maintain and enhance long-term meteorological and atmospheric monitoring within the southern Chesapeake Bay watershed to quantify key (e.g., nitrogen and mercury) contaminant loadings.
- Support biological monitoring of critical habitats (e.g., emergent wetlands, submerged aquatic vegetation) and the development of sentinel sites to address ecosystem responses to climate- and human-induced stress.

Objective 2. Determine linkages within and between coastal ecosystems and how linkages affect those systems.

Strategies:

- Determine how circulation patterns, mixing processes and exchange of water between regions (e.g., shoal, channel) of the York River system, its watershed and the Chesapeake Bay proper affect water quality, primary productivity and biological communities (e.g., benthic, nekton, plankton).
- Determine watershed (e.g., groundwater, stormwater runoff), airshed and Bay/oceanic material flux into the York River system.
- Examine how upland, shoreline and water management changes affect material flux and coastal ecosystems.
- Examine how episodic events (e.g., inter-annual variations in hydrologic budgets, large-scale storm events) and longer-term climatic changes affect material flux and coastal ecosystems.
- Examine rates and patterns of sea-level rise, subsidence and shoreline erosion and ecosystem responses to these processes within the York River system.
- Examine the relationship between environmental factors and the structure and function of coastal ecosystems (e.g., impacts of water clarity and temperature on seagrass beds; impacts of salinity and water level on wetland plant communities).

Objective 3. Promote, coordinate, track and support research and monitoring activities within Reserve boundaries and the York River system.

Strategies:

- Establish and maintain contact, and where appropriate, coordinate activities among groups with estuarine research interests.
- Identify research priority focus areas and encourage their investigation within Reserve components and the broader York River and Chesapeake Bay system.
- Utilize a permit system to approve and track research and related activities within Reserve boundaries.
- Continue to implement the NOAA/NERRS Graduate Research Fellowship program.
- Reserve associated faculty will continue to advise and mentor undergraduate and graduate students through participation in intern programs (e.g., NSF/VIMS Research Experience for Undergraduates, National Aquarium in Baltimore Conservation Intern Program) and through student advisory committee service.
- Seek external funding to advance research and monitoring activities.

Goal 2. Promote the effective management and conservation of natural and cultural coastal resources through informed decision-making.

Objective 1. Communicate results of research, environmental monitoring and best available science-based information to assist in improved coastal resource management.

Strategies:

- Serve in an advisory capacity to national, regional, state and local coastal resource management, research and education agencies, organizations and interest groups
- Provide the best available science-based information and skill building opportunities, with respect to priority needs, to coastal resource decision-makers and other appropriate audiences via a variety of formats including training workshops, sponsored conferences and developed information products.
- Develop, maintain and/or link to web-based data and information portals to manage and disseminate Reserve associated science and education information products, environmental databases, and associated metadata.
- Support the development and implementation of Bay-wide and specific tributary strategies and contaminant reduction plans in support of protection and restoration of water quality and habitats of concern.
- Participate in local (Virginia Estuarine and Coastal Observation System), subregional (Chesapeake Bay Observing System) and regional (Mid-Atlantic Coastal Ocean Observing Regional Association) Integrated Coastal and Ocean Observing System (ICOOS).

NERRS GRADUATE RESEARCH FELLOWSHIP PROGRAM

The Graduate Research Fellowship Program (GRF) supports students to produce high quality research in the reserves (Figure 1). The fellowship provides graduate students with funding for 1-3 years to conduct their research, as well as an opportunity to assist with the research and monitoring program at a reserve. Funds are available on a competitive basis and no more than two fellowships per designated reserve are allowed at any one time. Fellowships typically start on June 1 of each year. Awards may be used for salary, to defray the costs

Figure 1. NOAA/NERRS Graduate Fellow, conducting field studies at Goodwin Island. Photo credit: Kenneth Moore.

of living expenses, tuition, fees and/or research supplies. Students admitted to or enrolled in a full-time Masters or Doctoral program at U.S. accredited colleges and universities are eligible to apply. Students should have completed a majority of their course work at the beginning of their fellowship, and have an approved thesis research program.

Projects must address coastal management issues identified as having regional or national significance, relate to the reserve system research focus areas and be conducted at least partially within one or more designated reserve sites. Proposals must focus on one or more of the following areas: (1) eutrophication, effects of non-point source pollution and/or nutrient dynamics; (2) habitat conservation and/or restoration; (3) biodiversity and/or the effects of invasive species; (4) mechanisms for sustaining resources within estuarine ecosystems; and/or (5) economic, sociological, and/or anthropological research applicable to estuarine ecosystem management. Students work with the research coordinator or manager at the host reserve to develop a plan to participate in the reserve's research and/or monitoring program. Students are asked to provide up to 15 hours per week of research and/or monitoring assistance to the reserve; this training may take place throughout the school year or may be concentrated during a specific season.

NATIONAL MONITORING PROGRAM

It is the policy of CBNERRVA to implement each phase of the System-Wide Monitoring Plan initiated by NOAA's Estuarine Reserves Division (ERD) in 1989, and as outlined in the System-Wide Monitoring Program (SWMP) (NERR, 2007).

Phase I. Abiotic monitoring including water quality and meterological monitoring;

Phase II. Biological monitoring including submerged aquatic and emergent vegetation monitoring; and

Phase III. Landuse and habitat change including Reserve habitat and watershed land use mapping.

The SWMP provides standardized data on national estuarine environmental trends while allowing the flexibility to assess coastal management issues of regional or local concern. The principal mission of the monitoring program is to develop quantitative measurements of short-term variability and long-term changes in the integrity and biodiversity of representative estuarine ecosystems and coastal watersheds for the purposes of contributing to effective coastal zone management. The program is designed to enhance the value and vision of the reserves as a system of national reference sites. The program also takes a phased approach and focuses on three different ecosystem characteristics. These are:

- Abiotic Variables: The monitoring program currently measures temperature, specific conductance, dissolved oxygen, turbidity, pH, water level and atmospheric conditions (Figure 2). In addition, the program collects monthly nutrient and chlorophyll a samples and monthly diel samples at one SWMP data logger station. Each reserve uses a set of automated instruments and weather stations to collect these data for submission to a centralized data management office.
- Biotic Variables: The reserve system is focusing on monitoring biodiversity, habitat and population characteristics by monitoring organisms and habitats as funds are available.
- Watershed and Landuse Classifications: This component attempts to identify changes in coastal ecological conditions with the goal of tracking and evaluating changes in coastal habitats and watershed land use/cover. The main objective of this element is to examine the links between watershed land use activities and coastal habitat quality.

These data are compiled electronically at a central data management "hub," the Centralized Data Management Office (CDMO) at the Belle W. Baruch Institute for Marine Biology and Coastal Research of the University of South Carolina. They provide additional quality control for data and metadata and they compile and disseminate the data and summary statistics via the Web (http://cdmo.baruch.sc.edu) where researchers, coastal managers and educators readily access the information. The metadata meets the standards of the Federal Geographical Data Committee.

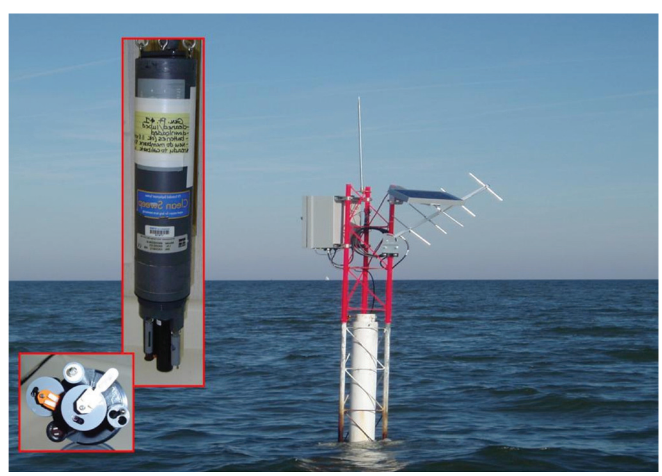

Figure 2. Goodwin Island SWMP continuous water quality monitoring station equipped with GOES satellite transmitter. Insert: YSI EDS water quality datalogger. Photo credit: William Reay.

ONGOING YORK RIVER MONITORING PROGRAMS

Meteorological and Streamflow Monitoring

- **CBNERRVA System-Wide Monitoring Program (SWMP).** CBNERRVA staff maintains meteorological monitoring stations at the Sweet Hall Marsh (established September 1998), Taskinas Creek (August 1997) and Goodwin Islands (January 2006) components of the Reserve. (Figure 3) Measured parameters include air temperature, relative humidity, precipitation, photosynthetic active radiation (PAR), barometric pressure, wind speed and direction. Real-time delivery of this data is currently available at selected stations. Selected data are available via the web at http://cdmo.baruch.sc.edu.

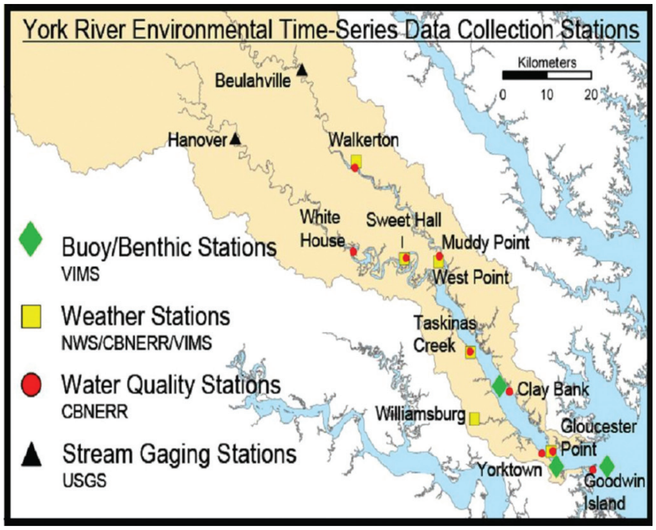

Figure 3. York River system continuous environmental data collection stations.

- **VIMS Meteorological Monitoring Program.** VIMS staff maintain a meteorological station at the Gloucester Point campus (May 1986) that is located approximately nine kilometers from Goodwin Islands. Measured parameters include air temperature, precipitation, PAR, and wind speed and direction. Selected data are available via the web at http:www.vims.edu/resources/databases.hrml.

- **National Streamflow Information Program.** The US Geological Survey (USGS) operates and maintains stream gages within the York River basin in order to provide long-term information on streamflow. Key stream gages above tidal influence on the Mattaponi and Pamunkey Rivers include the stations at Beulahville (USGS ID: 01674500; data available from 9/19/1941 to present) and Hanover (USGS ID: 0167300; data available from 10/1/1941). Selected data are available via the web at: http://www.water.usgs.gov/nsip.

- **National Atmospheric Deposition Program's National Trends Network (NADP/NTN) and Mercury Deposition Network (NADP/MDN).** CBNERRVA staff maintains the southern Chesapeake Bay NADP/NTN and NADP/MDN station (ID: VA98) located at Harcum, Va. The purpose of the network is to collect data on the chemistry of precipitation for monitoring of geographical and temporal long-term trends of concentrations and loading rates. Measured physical parameters include air temperature, precipitation, PAR, wind speed and direction. Measured chemical parameters include hydrogen ion activity (acidity as pH), sulfate, nitrate, ammonium, chloride, base cations (such as calcium, magnesium, potassium and sodium), total mercury and methyl-mercury. The NADP/NTN and NADP/MDN stations were established in August, 2004 and December, 2004, respectively. Realtime delivery of physical parameters is currently available at this station. Selected data are available via the web at http://nadp.sws.uiuc.edu.

Water Quality Monitoring

- **CBNERRVA System-Wide Water Quality Monitoring Program (SWMP).** CBNERRVA staff maintain fixed continuous water quality stations at the Goodwin Island (established October 1997), Taskinas Creek (September 1995), and Sweet Hall Marsh (January 1999) components of the Reserve and at Gloucester Point (March 2003), Clay Bank (January 2002) and White House (Marsh 2003) within the York River estuary system (Figure 3). Multi-parameter water quality monitors (model: YSI 6600 EDS) measured water temperature, specific conductance, dissolved oxygen, pH, turbidity, fluorescence and water depth at 15-minute intervals. In addition, the program collects monthly nutrient (nitrate, nitrite, ammonium, phosphate) and chlorophyll a samples at all primary SWMP stations and monthly diel samples at one SWMP station. Realtime delivery of this data is currently for selected stations via the NWS Hydrometeorological Automated System (HADS) webpage (http://www.nws.noaa.gov/oh/hads) and selected archived data is available via the web at the NERRS CDMO (http://www.cdmo.baruch.sc.edu) and VECOS http://www2.vims.edu/vecos).

- **VIMS Virginia Nearshore Water Quality Monitoring Program.** CBNERRVA and VIMS staff monitor nearshore surface water quality along a transect in the lower York River estuary. Measured parameters include air and water temperature, salinity, inorganic nitrogen and phosphorus, chlorophyll a, total suspended solids, PAR, light extinction coefficient, and color. Water quality samples have been collected bi-weekly since 1984.

- **Chesapeake Bay Program (USEPA and VaDEQ) York River Water Quality Monitoring Program.** Multi-depth samples are collected along a main channel transect in the York, Mattaponi and Pamunkey Rivers to support the multi-agency Chesapeake Bay Program. Station ID's: York River proper, the Pamunkey River and Mattaponi River. Measured parameters include water temperature, specific conductance, dissolved oxygen, pH, Secchi depth, chlorophyll a, pheaopigments, total suspended solids, dissolved inorganic and total nitrogen, total particulate nitrogen, dissolved inorganic and total phosphorus, particulate phosphorus, dissolved and particulate organic carbon. Water quality samples have been bi-weekly/monthly since 1984. Selected data are available via the web at http://www.chesapeakebay.net/data/index.htm.

- **Chesapeake Bay Program (U.S.EPA, NOAA, and VaDEQ) Enhanced Shallow Water Quality Monitoring Program.** CBNERRVA staff maintains additional fixed continuous (15 minute interval) water quality stations and conducts high frequency spatial water quality monitoring and mapping (using Dataflow) in a number of southern Chesapeake Bay tributaries. With respect to Dataflow, water quality and GPS location measurements are typically taken at 50-100 m intervals along the vessel track in both shallow (<1.5m) and channel areas. Fixed continuous stations and the Dataflow system utilize multi-parameter water quality monitors (model: YSI 6600 EDS) and measure water temperature, specific conductance, dissolved oxygen, pH, turbidity, chlorophyll fluorescence and water depth. Temporal sampling has typically been linked to SAV growing seasons (high salinity: March-November; low salinity: April-September) but recently has expanded to include late winter/spring to capture migratory fish spawning and nursery use in tidal freshwater and low salinity waters. In addition to York River efforts, continuous fixed water quality stations and Dataflow mapping activities occur within the James (2006-current), Rappahannock (2007-current) and portions of the Potomac (2007-current; fixed stations only). Selected data are available via the web at http://2/vims.edu/vecos.

  Note: In addition to Biological information, selected water quality and weather information is available for the cited biological monitoring programs below.

Biological Monitoring

- **VIMS Juvenile Fish and Blue Crab Trawl Survey** (Figure 4). Initiated in 1968, the primary goal of this survey is to develop indices of abundance, which measure the relative size of each year class of a target species. These indices indicate annual recruitment success or failure and help predict the future abundance of the stock. Fish and selected invertebrates (e.g., blue and horseshoe crab, squid) are collected monthly (except January and March) at stratified stations and historical fixed mid-channel stations within the York River estuary including the Mattaponi and Pamunkey River systems by the Institute's Fisheries Science Department. Selected data are available via the web at www.fisheries.vims.edu/research.html.

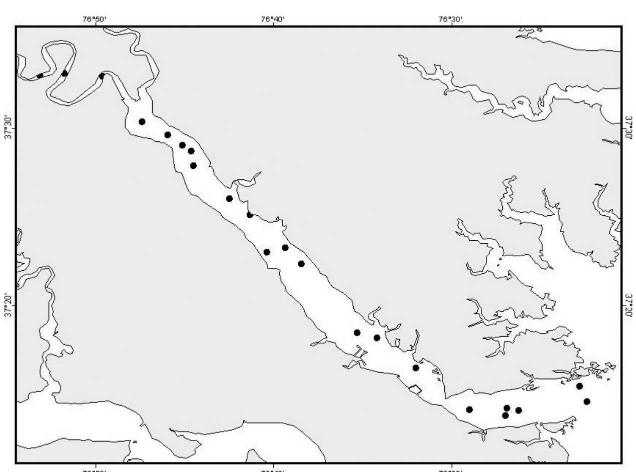

Figure 4. York River VIMS trawl survey stations. May 2005.

- **VIMS Juvenile Striped Bass Seine Survey.** Initiated in 1967-1973 and reinstated in 1980, the primary objective of this survey is to monitor the relative annual recruitment success of juvenile striped bass in the spawning and nursery areas of lower Chesapeake Bay. Fish and selected water quality information are collected on approximately five biweekly sampling periods from July through mid-September at primary index and auxiliary stations within the York River estuary including the Mattaponi and Pamunkey River systems by the Institute's Fisheries Science Department. Selected data are available via the web at www.fisheries.vims.edu/research.html.

- **CBNERRVA System-Wide Biological Monitoring Program (SWMP).** CBNERRVA staff participate in field monitoring of submerged aquatic vegetation and emergent wetlands within Reserve boundaries. Initiated in 2004, fixed transects located within SAV beds at Goodwin Islands and Gloucester Point are monitored in order to quantify SAV inter-annual variability in shoot density and distribution and identify any relationship to water quality (Figure 5). SAV transect monitoring occurs on a monthly basis, typically from April through October. Fixed transects within emergent wetland vegetation have been established at each of the Reserve components in order to measure plant diversity over time and a function of salinity regime. Monitoring of emergent wetland transects occurs during the summer on an approximately five year basis. CBNERRSVA is working in partnership with the NOAA Restoration Center in monitoring wetlands in the Sweet Hall Marsh Reserve Site to serve as a reference site for comparison with wetland restoration projects throughout the mid-Atlantic region.

- **Virginia Department of Health.** The VaDOH/Division of Shellfish Sanitation conducts the Shoreline Survey

Figure 5. Sampling along long-term fixed SAV biomonitoring transect. Photo credit: Kenneth Moore

and Seawater Sampling Programs along a series of sites in the York River estuary (which includes lower portions of the Mattaponi and Pamunkey River systems) in order to assess suitability classification of shellfish waters. The Seawater Sampling Program analyzes for fecal coliform bacteria at approximately monthly intervals while the Shoreline Survey inspects all properties within a drainage basin that are deemed capable of impacting shellfish waters at approximately 6-8 year intervals. Information regarding these programs is available via the web at www.vdh.state.va.us/environmentalhealth/shellfish.

- **VIMS Chesapeake Bay Submerged Aquatic Vegetation (SAV) Survey.** Initiated in 1971, SAV distribution, community types and density classes are mapped from aerial photography, primarily at a scale of 1:24,000. Bay-wide information is available for 1978, 1984 - 1987, and 1989 – 2007. Virginia western shore, lower and upper regions are available for 1971 and 1974, 1980-1981 and 1979, respectively. Data are stored in ArcInfo GIS coverages and information is available from the Institute's Biological Sciences Department at http://www.vims.edu/bio/sav.

RESEARCH POLICIES AND PROCEDURES

Research opportunities at Reserve sites are available to any qualified scientist, academician or student affiliated with a university, college or school, any non-profit organization, non-academic research institution (e.g., research laboratory, independent museum, and professional society), any private profit organization, and any state, local or federal government agency. Research opportunities will also be available to unaffiliated individuals who have the capability, facilities, and resources needed to perform the work. All researchers must complete and submit a CBNERRVA research application permit for work to be conducted within the Reserve system. In addition, research activities within the Taskinas Creek component of the Reserve require approval from the Virginia Department of Conservation and Recreation (VaDCR).

Research opportunities are available to all applicants without regard to manner of funding. Financial support for research may come from international, federal, state, local government, non-profit organizations, and from private individual sources. Examples of international sources include the United Nation's Man and the Biosphere, Food and Agriculture Organization and the Educational, Scientific and Cultural Organization programs. Federal sources may include USEPA, NOAA, National Marine Fisheries Service, National Sea Grant Program, the National Science Foundation, U.S. Department of Agriculture, and the U.S. Department of the Interior. Funding from state sources include the Virginia General Assembly and state resource management agencies, and localities. Non-profit organizations or foundation financial sources include the Virginia Environmental Endowment, The Nature Conservancy, Chesapeake Bay Foundation and the Alliance for the Chesapeake Bay.

RESERVE MONITORING AND RESEARCH NEEDS AND PRIORITIES

Because of proximity of graduate research institutions such as the Virginia Institute of Marine Science, School of Marine Science, College of William and Mary, and other universities such as Old Dominion University, Hampton University and the Virginia Commonwealth University, a great deal of research and monitoring is ongoing within the York system, in general, and the reserve sites, in particular. Of highest priority are those studies that further the Goals and Objectives of CBNERRVA to characterize and monitor the local ecosystems, to quantify spatial and temporal changes, to determine linkages within and between these systems and to determine how these linkages affect those systems.

The manifestations of global climate change and sea level rise on the local reserve system are of high priority for reserve research and monitoring activities. The impacts of these long-term factors have already been observed within York system; however, much more information is needed relative to their effects especially on the individual reserve sites. Some important topics include: effects on sediment transport, erosion and deposition; rates and impacts of salinity intrusion as well as freshwater inputs from storms on physical-chemical processes and biota including fish, benthos, wetlands and submerged aquatic vegetation; temperature impacts, especially those related to short-term extremes; rates and effects of euthrophication including atmospheric, non-point source, and ground water inputs; effects on hypoxia; impacts on habitat composition, diversity, function, recruitment and community succession.

Euthrophication mechanisms and effects especially that are related to landscape change and human development are another priority. The York River watershed is relatively undeveloped compared to other systems in the Chesapeake Bay; however the trend of increasing growth is unending. The fate and effect of elevated nutrient and sediment loads on the system are still not well understood. Much more work is needed on the interrelationships of euthrophication and the physics of the system. For example, the development of harmful algal blooms can be related to both the input of nutrients and the residence time in the system. Both nutrients and sediments affect SAV development and restoration, yet they interact with each other and with physical factors and sedimentalogical conditions.

Another priority area for research and monitoring includes the inputs, fates and effects of contaminates within the system. Atmospheric inputs of contaminants such as mercury are not well understood. The distribution, abundance, and impact of chlorinated hydrocarbons are thought to be widespread and significant, yet much is still unknown. The bioaccumulations and effects of contaminants including heavy metals, pesticides on the marine food web including the zooplankton are not well understood or studied. The York River is the site of a large oil refinery and paper mill but their effects are poorly studied. Human health issues have not been significant in the York system however there has been an increase in harmful algal blooms and increased potential for bacterial contamination from both human and animal sources. The quantification and tracking of viral and bacterial organisms affecting both humans and other organisms in the system are important topics for future work.

Invasive species have already had pronounced effects on the system. More work is needed on the quantification and identification of invasive species and their control. Although the distribution and abundance of many plant and animal components of the have been well studied, more work needs to be done on the benthos, zooplankton and algae.

Finally, more research and longer term monitoring is required relative to community and system restoration. There are large gaps in the knowledge of the relative efficacy of restoration activities; their cost, effectiveness and optimization of techniques. The role of founder species, diversity and succession in plant community restoration are not well known. Only recently have reference sites for freshwater wetland and seagrass communities been developed, from which restoration sites can be compared. The vegetation reference monitoring sites need to be expanded to include other communities along the entire system.

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