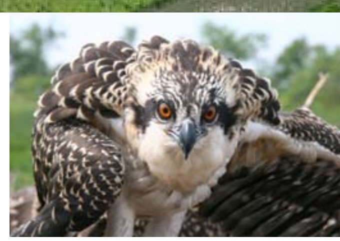
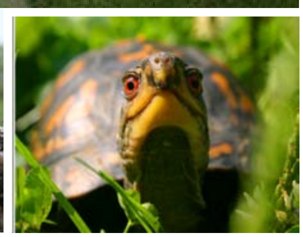
Chesapeake Bay
National Estuarine Research Reserve
Maryland

A SITE PROFILE





MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

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Chesapeake Bay National Estuarine Research Reserve
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 The Maryland Chesapeake Bay National Estuarine Research Reserve is part of the National Estuarine Research Reserve System (NERRS), established by Section 315 of the Coastal Zone Management Act, as amended. Additional information about the system can be obtained from the Estuarine Reserves Division, Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1305 East West Highway - N/ORM5, Silver Spring, MD 20910. CBNERR-MD is a partnership program managed by the Maryland Department of Natural Resources.

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EXECUTIVE SUMMARY

The main purpose of the site profile is to review and summarize the state of knowledge of the geological, physical, chemical, and biological components of Chesapeake Bay National Estuarine Research Reserve in Maryland (CBNERR-MD or Reserve). A Reserve characterization is presented for each of three Reserve components: Otter Point Creek, Harford County; Jug Bay, Prince George’s and Anne Arundel Counties; and Monie Bay, Somerset County; all of them located within the Maryland portion of the Chesapeake Bay. In addition to reviewing existing sources of information, this site profile includes a summary of the latest data results and information collected through the various research and monitoring projects conducted by the Reserve research program. Because of the geographic extent covered by this multi-component Reserve and the high volume of information generated within the entire Chesapeake Bay, this site profile is not intended to provide a complete review of all information generated around the Reserve components, but to present a local characterization that could serve as a starting point for the planning and execution of future research and monitoring efforts within CBNERR-MD. The site profile is structure by an introductory section about the Reserve and the National Estuarine Research Reserve System (NERRS), followed by three major sections, each corresponding to one of the Reserve components. As part of each of these sections, information is summarized regarding geological characterization, water and land use, weather and climate, water quality, habitat characterization, biological components, and a summary of current CBNERR-MD's research and monitoring efforts, needs, and priorities.

Overall, this site profile is intended to be primarily a technical document that provides a summary of scientific information for academic and agency researchers, graduate students, advanced undergraduates, and coastal resource managers, and anyone interested in learning more about the Reserve and the monitoring and research activities it supports.

AKNOWLEDGEMENTS

The Chesapeake Bay National Estuarine Research Reserve in Maryland would like to thank the following people for their valuable assistance during the development of the Reserve's site profile including the Otter Point Creek, Jug Bay, and Monie Bay site profiles. We extend special thanks to Ann Wheeler, Librarian of Maryland DNR, for her valuable support to this project by making many papers and publications accessible during the writing of this document. We would also like to thank our partners at Otter Point Creek, Jug Bay, and Monie Bay for providing information used during the development of this site profile including Elaine Friebele, Kriste Garman, Ron Gutberlet, Lindsay Hollister, Chris Swarth, and Donald Webster.

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CHAPTER I. INTRODUCTION TO THE MARYLAND CHESAPEAKE BAY NATIONAL ESTUARINE RESEARCH RESERVE (CBNERR-MD)

1.1 THE NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM PROGRAM

The Maryland Chesapeake Bay National Estuarine Research Reserve is part of the National Estuarine Research Reserve System (NERRS). NERRS was created by the Coastal Zone Management Act (CZMA) of 1972, as amended, 16 U.S.C. Section 1461, to augment the Federal Coastal Zone Management (CZM) Program. The CZM Program is dedicated to comprehensive, sustainable management of the nation's coasts. NERRS is a network of protected areas established to promote informed management of the Nation's estuaries and coastal habitats. NERRS currently consists in a network of 28 protected areas in 23 states and territories representing different biogeographic regions of the United States (Figure 1.1.1).

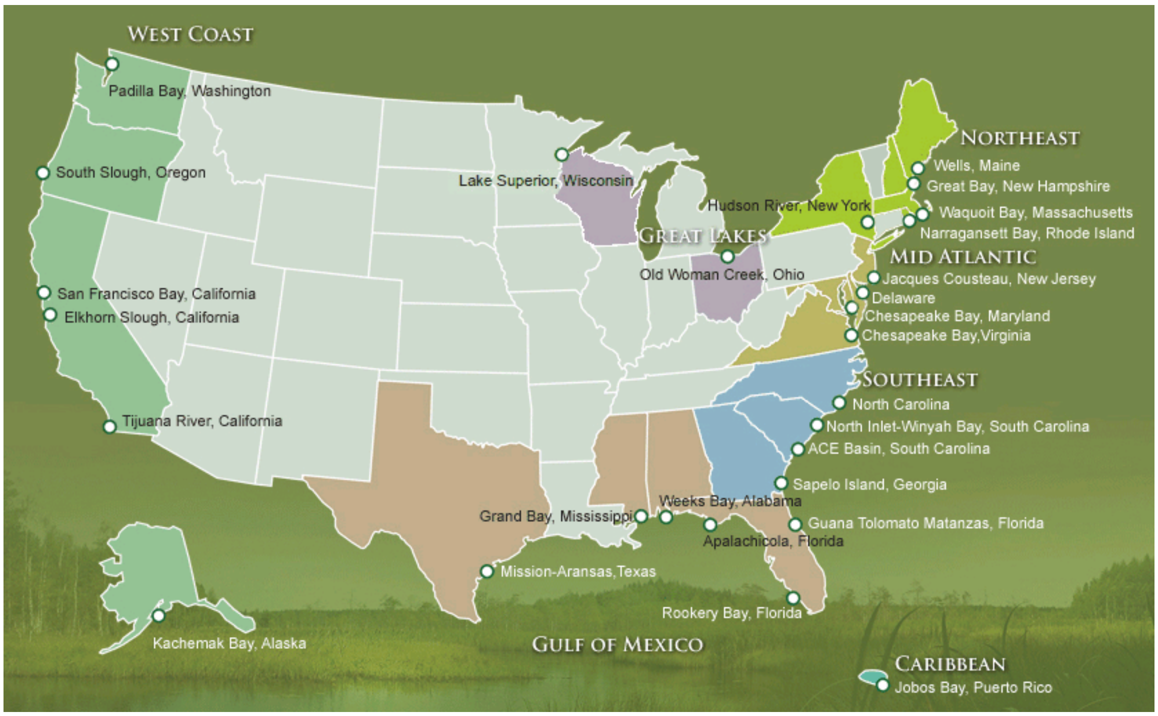


Figure 1.1.1 Map of National Estuarine Research Reserves. Courtesy of NOAA Estuarine Reserves Division (http://www.nerrs.noaa.gov/).

In its nation-wide efforts to improve coastal management, advance estuarine research, and educate current and future generations of coastal stewards NERRS has the following vision and mission (NERRS Strategic Plan 2011-2016):

NERRS Vision: "Resilient estuaries and coastal watersheds where human and natural communities thrive."

NERRS Mission: " To practice and promote stewardship of coasts and estuaries through innovative research, education, and training using a place-based system of protected areas."

The reserve system is a partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states. NOAA provides funding and national guidance. Each reserve is managed on a daily basis by a lead state agency or university, with input from local partners.

The NOAA interest is represented by the Estuarine Reserves Division (ERD), who coordinates the NERR system nationally and administers federal funds to individual Reserves. Although the management of a Reserve, including development of site-specific policies, is a state's responsibility, NOAA provides overall system policies and guidelines, cooperates with and assists the states, and reviews state programs regularly. The purpose of the NOAA review is to ensure that a state is complying with federal NERR goals, approved work plans, and reserve management plans. Programs currently implemented NERRS-wide include the system-wide monitoring program (SWMP), graduate research fellowship program (GRF), K-12 Estuarine Education Program (KEEP), and the Science Collaborative, a funding opportunity to connect science to decision making.

1.2 DESIGNATION OF THE CHESAPEAKE BAY NATIONAL ESTUARINE RESEARCH RESERVE IN MARYLAND

Maryland's Chesapeake Bay National Estuarine Research Reserve (CBNERR-MD or "the Reserve") was established by the Maryland Department of Natural Resources (Maryland DNR) in 1985 with Monie Bay in Somerset County being the sole component. In 1990 Otter Point Creek (in Harford County) and Jug Bay (in Prince George's and Anne Arundel Counties) were added to the Reserve. Together, these three Reserve components reflect the diversity of estuarine habitats found within the Maryland portion of the Chesapeake Bay (Figure 1.2.1). Each component is managed and protected to provide an environment for conducting research and monitoring, education, restoration, and coastal management training programs.

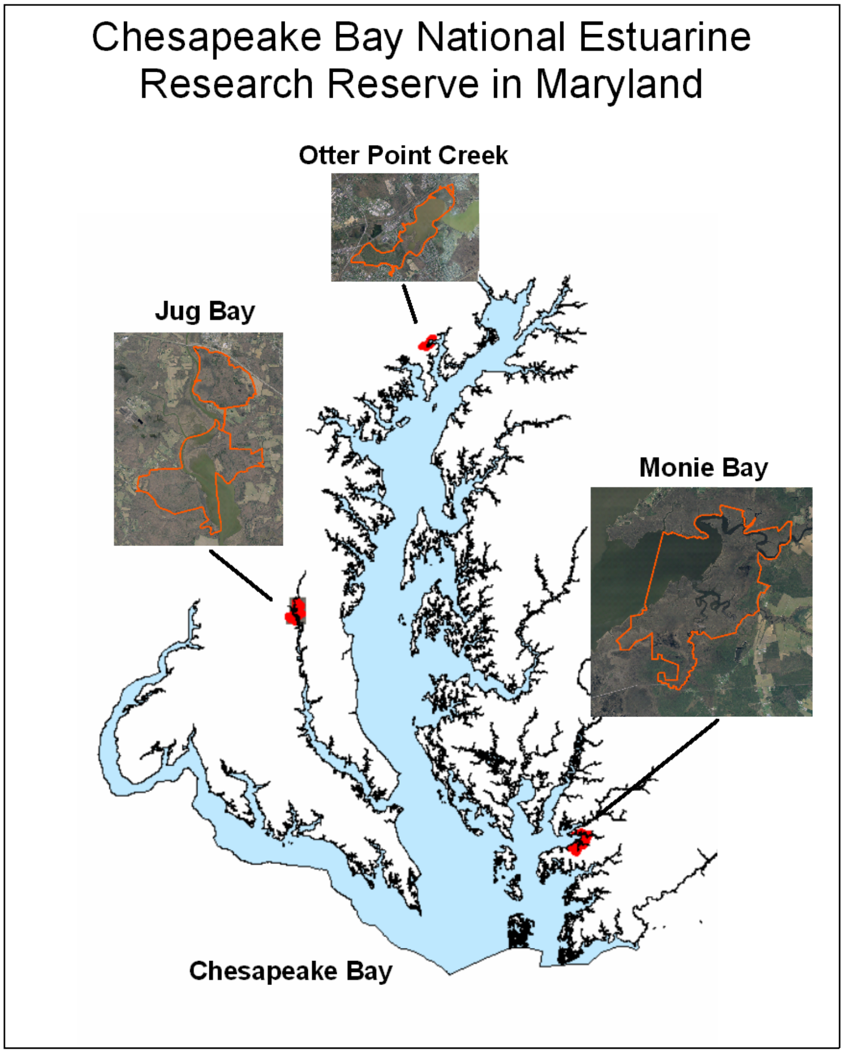


Figure 1.2.1 Location and 2011 boundaries of the three components of the Maryland Chesapeake Bay National Estuarine Research Reserve: Otter Point Creek, Jug Bay, and Monie Bay.

1.3 CBNERR-MD GEOGRAPHIC SETTING

The Chesapeake Bay, where the Reserve is located, is the largest estuary in the United States and is one of the most productive bodies of water in the world. It is situated in the mid-Atlantic area of the Atlantic coastal plain in the Chesapeake Bay subregion of the Virginian biogeographic region. The Chesapeake Bay is a drowned river estuary which formed as sea level rose after the last ice age over twelve thousand years ago and flooded the Susquehanna River valley (Grumet 2000). Roughly half of the Chesapeake Bay is in the State of Maryland and half in the Commonwealth of Virginia. The watershed of the Chesapeake Bay extends into four additional states: Delaware, Pennsylvania, New York and West Virginia and the District of Columbia.

The Bay is 180 miles (290 km) long and varies from 3 to 30 miles (5 to 48 km) wide. The average depth of the open Bay is 27.6 feet (8.4 m) and the average depth of the total Bay system including the tributaries is 21.2 feet (6.5 m). The shoreline of the Bay and its tributaries is approximately 8,100 miles (13,000 km) long, and about 4,000 miles (6,400 km) of this is in Maryland. Most of Maryland has a tidal range of 1 to 2 feet (0.3 to 0.6 m). Currents are moderate, usually well below 0.5 knots (0.9 km/hr), although they may reach 1.5 knots (2.8 km/hr) in bottlenecks or upper portions of the Chesapeake. Salinity typically ranges from 0 to 20 parts per thousand (ppt) in Maryland and reaches 30 ppt in Virginia. The bottom sediments range from clayey-silt to coarse-grained sand and gravel.

Artifact dating indicates that bands of territorial, semi-nomadic people lived in Maryland beginning in the Paleo-Indian Period (11,000-7,500 B.P.). Through the Archaic Period (7,500-1,000 B.P.) the people became more sedentary. Populations climbed as food sources increased with the formation of the Chesapeake Bay and general warming of the climate. During the Woodland Period (1,000 B.P.-A.D. 1,600) people became even more sedentary and living groups changed from temporary hamlets to permanent villages.

European settlement marked the beginning of dramatic changes for the Bay area. The first record of a European visit to the Bay was written by Brother Carrera, a Spanish priest, in 1572. The first European settlement on the Bay was Jamestown, Virginia, founded in 1607. In 1634, the first European settlers in current-day Maryland landed on St. Clements Island and then founded St. Mary's City. Tobacco imported from the West Indies flourished in the rich soil of the Bay area, and the hope of profit and a new life attracted a multitude of Europeans. Subsequently thousands of Africans were transported to Maryland by slave traders to provide free labor for the tobacco-based economy. Introduction of the plow in the 1790s initiated the largest impact of settlement-soil erosion. Sediments entering the Bay and its tributaries greatly increased, eventually closing off several port cities. Erosion and the deposition of sediments remain an ongoing problem. Shipping, shipbuilding, canning and the seafood industry became major industries for the area.

By 2000 Maryland's population exceeded 5,375,000. Most of the population in the state is concentrated around Baltimore (Maryland) and Washington, D.C. Main employments include construction, retail trade, services, and state and federal government. The Bay system is economically important for shipping, commercial fishing, recreation, tourism, and real estate value.

The Chesapeake Bay region is characterized by a humid, moderate, continental climate with warm humid summers and cold, but not severe, winters. Westerly winds prevail in the mid-Atlantic region of the U.S., bringing most of the weather systems from west to east. The Appalachian Mountains in western Maryland modify weather patterns coming in from the west. This phenomenon combines with the presence of the Chesapeake Bay and the Atlantic Ocean to create moderate weather in the area. Precipitation is fairly uniform throughout the year with August being the wettest month and February the driest. Normal annual precipitation varies from thirty-six inches to forty-seven inches (91 cm to 119 cm) in different areas of the state. During the colder months, high and low pressure systems alternate. This results in surges of warm, moist air from the south and east, and cold, dry air from the north and west. These changes in wind direction can cause the weather to change radically from one day to the next. Heavy precipitation during the cold time of year is generally the result of low pressure systems moving north or north-eastward along the Atlantic coast. During the warmer months the Bermuda High, a large semi-permanent subtropical high pressure system, spreads warm humid air northward over the area from the south and southeast. Heavy precipitation during this time of year generally falls in the form of thunderstorms, and most of these occur from May to August.

The broad range of environmental conditions in the Chesapeake Bay results in a wide variety of ecosystem types and, in turn, in a tremendous diversity of life. This is the home of a broad variety of marshes: estuarine river marshes (fresh and brackish), estuarine bay marshes (fresh, brackish, and salt), and coastal embayed marshes. These marshes regulate river flow, help prevent flooding of upland areas, sequester nutrients and other pollutants, and provide essential habitats and nursery areas for Chesapeake Bay living resources such as fish, shellfish, crabs, and waterfowl.

1.4 THE RESERVE MISSION STATEMENT

The mission of CBNERR-MD is:

"to improve coastal resource management by increasing scientific understanding of estuarine systems and making estuarine research relevant, meaningful, and accessible to managers and stakeholders."

The Reserve as a whole works towards achieving its mission through its different programs: administration, research, education, coastal training, and stewardship.

Administration: Seeking resources including funding to enhance all Reserve program sectors, cultivating new and fostering existing relationships with partners, and supporting staff professional development.

Research and Monitoring: Conducting, coordinating, and translating relevant research and monitoring information to improve decision-making.

Education: Building estuarine and environmental literacy through programs with teachers, students, and communities that will connect them to the Chesapeake Bay and move them to take action toward its protection and restoration.

Coastal Training: Facilitating informed and improved decision-making by making estuarine research relevant, meaningful, and accessible to managers and stakeholders. The initial focus is to develop Coastal Trainings that help elected and appointed officials and their staff make wise decisions and find solutions using sound estuarine science.

Stewardship: Protecting, managing and restoring three ecologically-valuable estuarine sites and providing stewardship opportunities for Marylanders.

Reserve staff work with local communities and regional groups to address natural resource management issues, such as climate change, non-point source pollution, habitat restoration, and invasive species. Through integrated research and education, the Reserve helps communities develop strategies to deal successfully with these coastal resource issues. The Reserve provides adult audiences with training on estuarine issues of concern in their local communities. It offers field classes for K-12 students and support teachers through professional development programs in marine and estuarine education. The Reserve also provides long-term water quality monitoring as well as opportunities for both scientists and graduate students to conduct research in a "living laboratory" (NERRS 2009).

1.5 CBNERR-MD MANAGEMENT STRUCTURE AND PRIORITIES

The management structure of CBNERR-MD presents opportunities and challenges that may be unique among other designated reserves in the NERRS because of the multi-component nature of this Reserve. With three components CBNERR-MD encompasses multiple habitat types and a variety of management issues. The Reserve is managed to achieve local, state and federal objectives. Reserve staff coordinates and conducts activities and programs which are of interest to one or more sites. Each component also has site-driven programs to meet its research, monitoring, educational, and general use needs.

The three geographically distinct components of the Reserve are separated by a significant distance. Each of these components is also located in a different local jurisdiction, which is the primary historical reason that each of the Reserve component sites has a different site ownership and management as summarized in Table 1.5.1. Each of these site owners participates in the Reserve through a Memorandum of Understanding with Maryland DNR.

Table 1.5.1 Management structure of the Maryland Chesapeake Bay National Estuarine Research Reserve components.

Reserve Component	Site	Owner	Site Management Responsibility
Otter Point Creek	Leight Park	Harford County	Department of Parks and Recreation
	Melvin G. Bosely Conservancy	Izaak Walton League of America (IWLA) Harford County Chapter	IWLA and Harford County Department of Parks and Recreation
Monie Bay	Deal Island Wildlife Management Area	Maryland Department of Natural Resources	Wildlife and Heritage Division
Jug Bay	Jug Bay Wetlands Sanctuary	Anne Arundel County	Department of Recreation and Parks
	Patuxent River Park	Maryland-National Capital Park and Planning Commission	Department of Parks and Recreation

As the Nation's largest estuary and a region experiencing substantial population growth, increasing development pressures, and land use changes, as well as subsidence and sea level rise, the Chesapeake Bay region is confronted with numerous management issues. The Reserve's programs are primarily focused on five management issues (Maryland DNR 2008).

Two categories of key stressors require management actions to reduce their impacts on estuarine systems:

- Population growth and development, increases in impervious surface, the loss and alteration of habitat and vegetation in the watershed, and increases in point source flows. These losses and alterations affect both: 1) hydrologic and pollutant inputs, and 2) living resource food web dynamics and community structure.

- Climate change, subsidence, erosion, flooding and inundation, and the altering/hardening of shoreline structure. These issues have both ecosystem and socio-economic implications. Delaware and Maryland are the third and fourth most vulnerable states to sea level rise after Louisiana and Florida, and the Monie Bay component is located in one of the most vulnerable counties in Maryland.

Management actions will aim to help protect and restore:

- Sustainable living resource animal populations and communities (terrestrial and aquatic, including fish, reptiles, amphibians, birds, mammals and invertebrates). Reserve programs will address issues related to reduced population numbers and species diversity. In addition to the stressors listed above, bacterial contamination, toxic contamination, and invasive species affect these populations and communities.

- Important habitats including Submerged Aquatic Vegetation (SAV – bay grasses), emergent plant, and native terrestrial plant communities. Losses and changes to these communities will be investigated and addressed. In addition to the stressors listed above invasive species can adversely affect these plant communities and reduce habitat value.

- Healthy water quality/habitat. Key factors that degrade water quality include excessive nutrients and sediments. For example, these factors can cause low dissolved oxygen, less desirable phytoplankton and zooplankton assemblages, and Harmful Algal Blooms.

The Chesapeake Bay is arguably one of the most studied and managed bodies of water in the United States. Multiple programs are run by various groups through out the watershed. This situation provides unique opportunities as well as challenges. Communication with other programs within Maryland DNR such as the state coastal program and with other state agencies is essential, including Maryland's Department of Planning, Department of Environment, Department of Agriculture, and Department of Transportation. Key partners in addition to the Reserve component partners and NOAA/Estuarine Reserves Division include local universities and colleges, informal education centers such as the National Aquarium in Baltimore and the Salisbury Zoo, Sea Grant, Critical Area Commission, Tributary Strategies, Chesapeake Bay Trust, Environmental Protection Agency Chesapeake Bay Program, NOAA Chesapeake Bay Program and other NOAA offices, the Mid-Atlantic Coastal and Ocean Regional Association, municipal and county agencies, the business community and other local entities including citizen groups and non-profits. The Reserve works to leverage opportunities and to encourage and facilitate collaboration to achieve the Reserve's mission.

1.6 CBNERR-MD RESERVE COMPONENTS

Today, the three CBNERR-MD components incorporate a total of 4,962 terrestrial acres and 1,268 acres of open water (Table 1.6.1). Maryland's multi-component Reserve reflects the diversity of estuarine habitats found within the Maryland portion of the Chesapeake Bay. The Reserve's three components are in geographically distinct locations as shown in Figure 1.1.1.

Table 1.6.1 Acreage of Maryland Chesapeake Bay National Estuarine Research Reserve components.

Acreage Summary			
Reserve Component	**Land**	**Open Water**	**Total**
Otter Point Creek	475	261	736
Jug Bay	1,817	251	2,068
Monie Bay	2,670	756	3,426
Total	4,962	1,268	6,230

1.6.1 Otter Point Creek

The Otter Point Creek component (OPC) is located in densely populated Harford County, near the town of Edgewood and near the U.S. Army's Aberdeen Proving Grounds. A large area of suburban road network is found in the watershed that flows into Otter Point Creek. Otter Point Creek is a small arm of the larger Bush River, which is a tidal portion of the Upper Chesapeake Bay. The core area of the OPC component encompasses one of the few tidal fresh marshes in the upper Chesapeake Bay that is still in a relatively natural and undisturbed condition. It also includes forested wetlands, upland hardwood forests and shallow, open estuarine waters. A high diversity of floral and faunal populations is found here, including submerged aquatic vegetation (bay grasses), waterfowl, and mammals.

The need for public education has been and will continue to be a major focus for the Reserve at this component along with coastal training, research and monitoring, stewardship, and restoration activities. Future management of the component will need to consider how to mitigate the effects of a rapidly growing population and increased development in the watershed. Increasing sediment and nutrient loads at OPC and within the Bush River system are an immediate concern.

1.6.2 Jug Bay

The Jug Bay component consists largely of a shallow, tidal fresh embayment of the Patuxent River, fringing marshes and feeder streams, and adjacent uplands. This Reserve component is near the mid point of the 175-km (109-mile) long Patuxent River watershed; surrounding areas have a mix of natural area, agriculture and development. Jug Bay is located relatively close to urban centers and is under development pressure, yet it is still relatively pristine due to preservation efforts along the Patuxent River.

The core area of the Jug Bay component consists of open water of the Patuxent River and Jug Bay, the tidal portions of Two Run, Black Walnut Creek, Western Branch and the fringing tidal wetlands along the shoreline. Since this component incorporates property in two counties, the core area in each county was delineated to represent an ecological subunit. Together, these two areas complement each other to form a more diverse, complete ecological unit. The waters of the river and Jug Bay unify the tidal wetlands systems on opposite sides of the shore.

The Jug Bay core area provides habitat for a wide diversity of flora and fauna, including over 200 species of birds. Jug Bay is designated as an Audubon Important Bird Area (IBA); over 100 native species are documented as confirmed or probable breeders. Twenty-two species of ducks use the site's wetlands for breeding and wintering. This is also the farthest upriver spawning area for striped bass (*Morone saxatilis*) in the Patuxent River. Several rare and endangered species are found in this area.

The Patuxent River is eutrophic due to large inputs of anthropogenic sources of nitrogen and phosphorus from wastewater treatment plants, failing septic systems, agricultural fertilizers, urban/suburban runoff, and atmospheric deposition. Water quality at the site is driven in part by the vast tidal freshwater marshes that have the capacity to help reduce contaminants and aid in biological processing at the site. Additionally, water quality is heavily influenced by the rapid movement of water and tidal flux associated with the mainstem of the Patuxent River. The mainstem water quality is heavily influenced by a large wastewater treatment plant that discharges treated effluent into Western Branch, a tidal tributary of the Patuxent River with confluence just above Jug Bay. As of 2003, the Western Branch Wastewater Treatment Plant discharges over 20,000,000 gallons per day (20 mgd) and its total capacity equals 30 mgd (Maryland DNR 2003). The wetlands at Jug Bay help improve water quality via the microbially-mediated process of denitrification that takes place in tidal sediments, and the seasonal uptake of nutrients by emergent and submerged aquatic plants during the growing season.

Future management of the area should focus on (1) effects of land use change and mitigation efforts on upstream waters; (2) impacts of wastewater treatment effluent on local water quality; (3) effects of migratory waterfowl on marsh vegetation, nutrient concentrations and fecal coliforms at the site, and (4) how changes in sediment accretion rates and/or sea level rise may alter marsh habitat.

1.6.3 Monie Bay

The Monie Bay component lies along the northern side of the Deal Island peninsula in Somerset County. It is comprised of mesohaline saltwater marshes, tidal creeks, pine forests and shallow open water that provide habitat for many species. The open water of tidal Monie Bay merges with the Wicomico River before reaching Tangier Sound and the Chesapeake Bay.

The Monie Bay watershed is relatively undeveloped with limited agricultural activities, including chicken farming. Water quality at the site is driven in part by tidal flow from the Chesapeake Bay mainstem as well as vast tidal saltwater marshes and creeks that make up the watershed. The site is comprised of three main tidal tributaries, Little Monie Creek, Monie Creek and Little Creek, which range in salinity from mesohaline to oligohaline. In addition to their range in salinity, they also differ in the amount of development (specifically agricultural) that impacts each creek. Monie Creek is the largest of the three creeks and has a large freshwater input as well as high agricultural input. Little Monie Creek is slightly smaller with less freshwater input causing salinity to be higher at 10-12 ppt and has moderate agricultural input. Little Creek is the smallest of the three tributaries and has less freshwater inflow and increasing tidal influence with salinity ranging from 12-13 ppt and no agricultural or other development within the watershed. The three different tributaries with their differences in salinity and agricultural input provide a framework for a natural experimental design that lends itself to comparative research.

Maryland is the third most vulnerable state to sea level rise in the United States, and Somerset County is one of the most vulnerable counties to sea level rise in Maryland. Subsidence, relative sea level rise, and erosion are important processes affecting Monie Bay. Future management of the area should focus on (1) effects of land use, land use change, and best management practices on the tidal creeks; (2) impacts of varying water quality on aquatic species; and (3) how changes in sea level rise may impact the marsh ecosystem.

1.7 CBNERR-MD RESEARCH AND MONITORING PROGRAMS

Currently, there are two NERRS system-wide efforts to fund estuarine research and monitoring activities—the Graduate Research Fellowship Program (GRF) and the System-wide Monitoring Program (SWMP). In addition, the National Estuarine Research Reserve's Science Collaborative, initiated in 2009 was designed to put NERRS-based science to work in coastal communities. This program is administered by the University of New Hampshire and funds and provides competitive grants to support Reserve-led research projects that bring scientists, intended users of the science, stakeholders, educators, and trainers together to address problems related to coastal pollution and habitat degradation in the context of a changing climate.

1.7.1 Graduate Research Fellowship Program

The Graduate Research Fellowship Program supports students to conduct high quality research in the reserves. The fellowship provides graduate students with funding for one to three years to conduct their research, as well as an opportunity to assist with the Research and Monitoring Program at the host reserve. Projects must address coastal management issues identified as having regional or national significance; relate them to the reserve system research focus areas; and be conducted at least partially within one or more designated reserve sites. Currently, proposals must focus on the following areas:

- Eutrophication, effects of non-point source pollution and/or nutrient dynamics
- Habitat conservation and/or restoration
- Biodiversity and/or the effects of invasive species
- Mechanisms for sustaining resources within estuarine ecosystems
- Economic, sociological, and/or anthropological research applicable to estuarine ecosystem management

Students work with the Research Coordinator or Reserve Manager at the host reserve to develop a plan to participate in the reserve's research and/or monitoring program. Students are encouraged to provide up to 15 hours per week of research and/or monitoring assistance to the reserve; this effort may take place throughout the school year or may be concentrated during a specific season.

1.7.2 System-Wide Monitoring Program

It is the policy of CBNERR-MD to fully implement the System-Wide Monitoring Plan initiated by ERD in 1989:

- Environmental Characterization, including studies necessary for inventory and comprehensive site descriptions
- Site Profile, to include a synthesis of data and information
- Implementation of the System-wide Monitoring Program

The System-wide Monitoring Program provides standardized data on national estuarine environmental water quality and weather 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 references sites. Currently, the program focuses on three different ecosystem characteristics.

1) Abiotic variables: The monitoring program currently collects high resolution data (collected every 15 minutes) on pH, conductivity, salinity, temperature, dissolved oxygen, turbidity, water level and atmospheric conditions. 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 the Centralized Data Management Office (CDMO). At some of the CBNERR-MD stations the data are telemetered so that they are accessible in near-real time through both the Eyes on the Bay and CDMO web sites.

All SWMP abiotic data from all reserves are compiled electronically at the central data management “hub” CDMO, located at the Belle W. Baruch Institute for Marine Biology and Coastal Research of the University of South Carolina. CDMO provides additional quality control for data and metadata and they compile and disseminate the data and summary statistics via the Internet (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.

2) Biotic variables: NERRS is focusing on monitoring biodiversity, habitat and population characteristics by monitoring organisms and habitats as funds are available. Ongoing programs at CBNERR-MD include underwater grass (SAV) monitoring, emergent vegetation monitoring, and volunteer-driven fish, marsh birds, and herp monitoring.

3) Watershed habitat mapping and change: This effort 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.

1.7.2.1 Implementation of the System-wide Monitoring Program (SWMP) at CBNERR-MD

The CBNERR-MD Research Program aims to provide accurate and reliable baseline information that is useful in detecting changes over time and determining spatial heterogeneity of environments at each component. The NERR System-wide Monitoring Program's protocols are followed for weather and water quality monitoring. Additionally, efforts are made to standardize all monitoring protocols and approaches at all sites, both in the tidal and non-tidal waters, to allow for cross-site comparison and use at the State, regional and national level. Monitoring efforts are done in close cooperation with the DNR at the State level and NERRS at the national level.

The Reserve participates fully in the monitoring of abiotic parameters of SWMP (monitoring water quality and weather parameters) for long-term change and short-term variability. Water quality monitoring efforts remain a high priority due to the local, regional and national importance of the data. Shallow water habitat monitoring, including submerged aquatic vegetation (underwater grasses) and marsh vegetation, is also a high priority at all CBNERR-MD components. Emphasis is placed on efforts to improve the knowledge of shallow water systems with particular attention on tracking water quality that is useful to the EPA's Chesapeake Bay Program and their efforts to assess shallow water based on criteria for dissolved oxygen, water clarity, and chlorophyll *a* concentrations.

The CBNERR-MD Research Program includes a variety of biological monitoring studies that go beyond macrophytes, and includes macroinvertebrates (freshwater), nekton, birds, reptiles, amphibians, and mammals. Studies related to climate change, subsidence, erosion, accretion, and sea level rise, and associated ecosystem responses have become a heightened priority. Since 2008, CBNERR-MD has moved forward with the establishment of core infrastructure to make of this Reserve a Sentinel Site for climate change. This is a NERRS-wide effort lead by NOAA-ERD for the detection and monitoring of climate change impacts on coastal ecosystems. It provides a unique platform to fulfill existing information and monitoring gaps that would support initiatives to better adapt and mitigate to climate change impacts in the coastal zone. Also, by 2014, CBNERR-MD plans to complete a land use characterization of the Reserve and its watershed.

Applied research activities that aim at meeting management needs are strongly encouraged. Efforts are made to find creative ways and develop partnerships that will help fund management driven research questions at the Reserve. Research activities that allow for educational outreach, volunteer involvement and stewardship are particularly important.

1.8 RESERVE FACILITIES

Reserve staff has office space in the Maryland DNR headquarters, which is the Tawes State Office Building in Annapolis, Maryland. This is central to the three Reserve components and is approximately 48 km (30 miles) from Jug Bay, 80 km (50 miles) from Otter Point Creek, and 161 km (100 miles) from Monie Bay.

In addition to the main office in Annapolis, the Reserve also uses building space at the Jug Bay and Otter Point Creek components. Monie Bay has very limited facilities that are mainly used to keep research equipment. The Anita C. Leight Estuary Center, in Harford County's Leight Park, which is part of the Otter Point Creek component, is one of those spaces (Figure 1.8.1). In addition to serving Harford County's needs for environmental education and outreach, this facility provides Reserve office space and the capability for conducting and coordinating education, research, monitoring and public outreach activities.

Figure 1.8.1 Anita C. Leight Estuary Center, Otter Point Creek.

Another important facility in the Reserve is the Visitor Center and headquarters building in Patuxent River Park in Prince George's County, which constitutes part of the Jug Bay component. These facilities are operated by the Maryland National Capital Park and Planning Commission. These facilities, including an education laboratory (Figure 1.8.2), are valuable staging areas for research, monitoring and education/outreach.

Figure 1.8.2 Education laboratory, Patuxent River Park in Prince George's County.

A third key facility for the Reserve is the McCann Wetlands Study Center in Anne Arundel County's Jug Bay Wetlands Sanctuary, which is also part of the Jug Bay component (Figure 1.8.3). In addition to serving as the headquarters and central programming hub for the

Sanctuary, this facility is a key staging facility for the Reserve's efforts at Jug Bay including research, monitoring and education/outreach.

Figure 1.8.3 McCann Wetlands Study Center in Anne Arundel County's Jug Bay Wetlands Sanctuary (southern area – original sanctuary).

A fourth key facility is the Plummer House in Anne Arundel County's Jug Bay Wetlands Sanctuary's northern area, the Glendening Preserve. This area was incorporated into the Reserve with the 2008 Management Plan (Maryland DNR 2008). This facility provides office space, meeting space, and a staging ground for coastal training, volunteer, research and education programs. This facility also includes demonstration bayscaping developed as part of a Coastal Training Program, and most of the electricity for this building is provided by a demonstration solar panel project completed in 2010 (Figure 1.8.4).

Figure 1.8.4 (a) Plummer House in Anne Arundel County's Jug Bay Wetlands Sanctuary (northern area – Glendening Preserve). (b) Anne Arundel County Executive John Leopold at Plummer House solar panel dedication in 2010.

CHAPTER 2. THE ECOLOGY OF THE OTTER POINT CREEK ESTUARY

2.1 OVERVIEW

Otter Point Creek (OPC) was designated as a component of the Chesapeake Bay National Estuarine Research Reserve in Maryland (CBNERR-MD) on October 4, 1990. With a total of 299 hectares (736 acres), including land and water, the OPC Reserve is the smallest of the three CBNERR-MD components (Figure 2.1.1). OPC, a tributary of the Bush River, is located at approximately Latitude 36° 26' North, Longitude 76° 18' West. Above the head of tide, OPC is known as Winters Run. In addition to Winters Run, another tributary that enters the component boundaries is HaHa Branch. The entire component is fresh to oligohaline and is strongly dominated by freshwater and sediment input from the watershed.

The OPC component includes freshwater tidal marshes, riparian forest, upland hardwood forests and shallow, open estuarine waters. The core area consists of an estuarine wetland complex which includes tidal marshes east of some old sewage lagoons, tidal creeks and guts running through the marshes, and open water extending eastward to Otter Point. This core area encompasses one of the few remaining freshwater tidal marshes in the upper Chesapeake Bay that is still in a relatively natural and undisturbed condition. A high diversity of floral and faunal populations is found here, including emergent and submerged aquatic vegetation, waterfowl, and mammals.

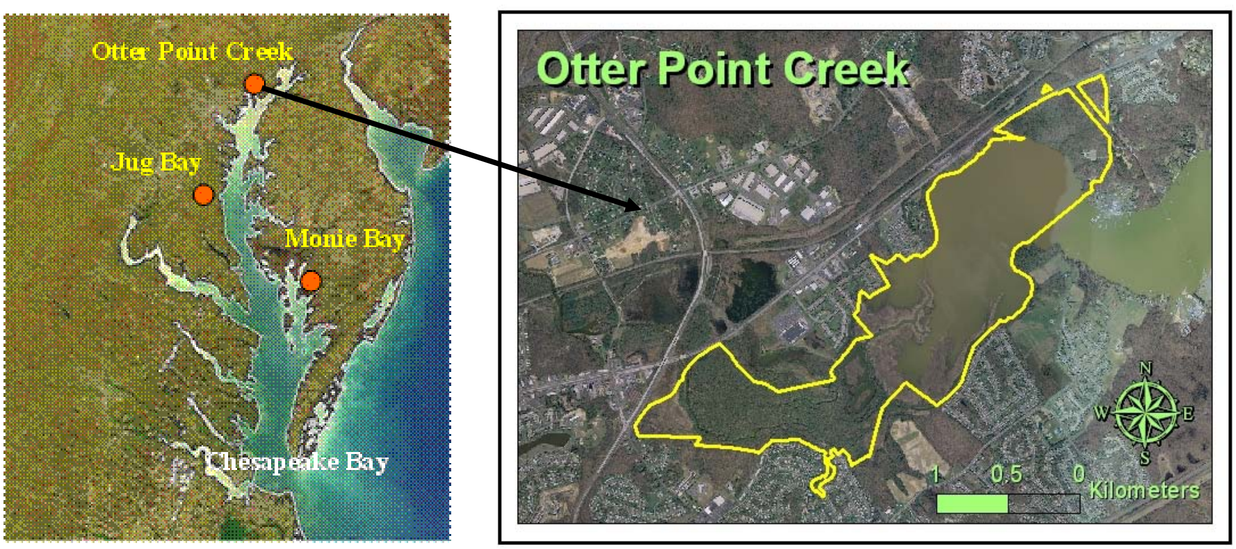


Figure 2.1.1 Geographic location and boundaries of OPC, component of the Chesapeake Bay National Estuarine Research Reserve in Maryland.

The OPC Reserve is located in the densely populated Harford County, a rapidly urbanizing suburb of Baltimore located along the major travel corridor between Baltimore and Washington D.C. to the south and the urban areas of Pennsylvania, Delaware, and New Jersey to the north and east. In addition to several major highways (I95, U.S. 1, and U.S. 40), Conrail Tracks pass the component to the north and Amtrack tracks pass to the south. The construction of several of these transportation corridors has altered the drainage patterns in the watershed and has influenced the formation of the marsh. Figure 2.1.2 shows the large area of suburban road network found in the watershed that flows into OPC.

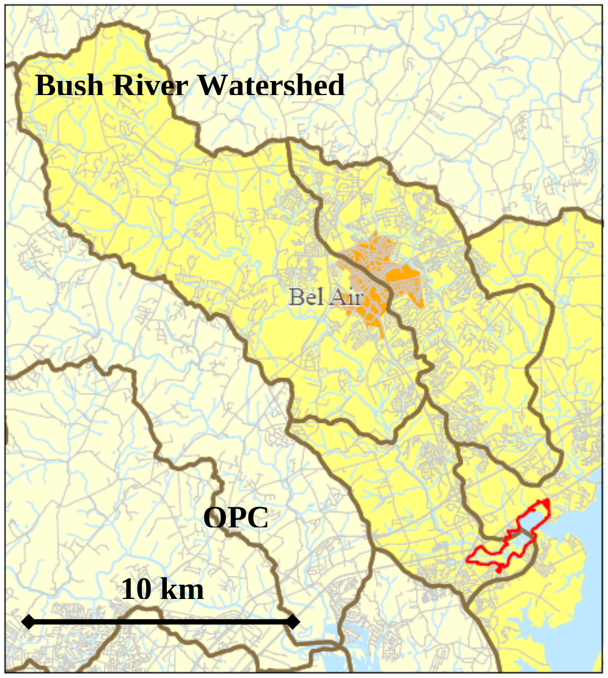


Figure 2.1.2 Suburban road network found in the Bush River watershed, which flows into OPC.

Because of the pressure of urbanization in the immediate vicinity and in the upstream watershed, the OPC estuary is facing potential threats from alterations in hydrology, sedimentation patterns, and anthropogenic physical impacts. Under current conditions, environmentally sound management activities are necessary in order to preserve the ecological integrity of this important tidal freshwater ecosystem.

Public access to OPC is managed by the two property owners.

1. The Harford County Chapter of the Izaak Walton League of American owns the Melvin G. Bosely Wildlife Conservancy. The Conservancy forms the western portion of OPC, and can be reached from Route 40 via Edgewood Road, Hanson Road, and Perry Avenue.
2. Harford County owns Leight Park, which is the eastern portion of OPC. The Park can be reached by taking Otter Point Road south from Route 40. Access to open water is limited by accessibility from land and by intermittent shallow water caused by changing tides.

2.2 HISTORICAL LAND USE AND CULTURAL RESOURCES

The history of land use in the Winters Run watershed including OPC has been summarized by Hilgartner and Brush (2006) and Hilgartner (1995). Land use history of the upper Chesapeake shore in general and its impact on the estuary was described by Brush and Hilgartner (2000) and Davis (1986). These references provide the baseline of information for what follows with some annotation.

Human disturbance before European settlement in the 17th century was minimal (Custer 1986). Populations of no greater than 6,000 along the entire Maryland coastline of the Chesapeake Bay (Ubelaker and Curtin, 2001) cleared less than 1% of forests (Brush 1984). Anthropogenic fire within the uppermost reaches of Winters Run watershed may have been important in producing "grasslands or grassland savannahs" (Marye 1955a, 1955b). A charcoal peak found in sediments deposited during the 13th century in OPC suggests increased wildfire or human-set fires during that time (Hilgartner 1995).

Harford County was the home to a flourishing Native American population for at least 5,000 years. Traces of Susquehannock, Conoy, and Massawomek habitation have been found in the tidewater regions near the Chesapeake, on now-submerged islands of the Susquehanna River, and along the streams and creeks across the County (Harford County 1998).

Campsite clearings during the Early and Middle Woodland Period of Native Americans (1000 B.C. to 1000 A.D.) were located near wildlife resources, migration routes, and riparian resources, especially near embayments of small streams and rivers (Gardner et al. 1988; Frye 1986). An archaeological site from this period existed at the location of the present Edgewood Meadows housing development (Gardner et al. 1988). Maize agriculture appeared in the region around 800 A.D. and supplemented hunting and gathering activities as a means of supplying food for the local population. The development of agriculture led to larger more long term settlements in areas near both agricultural lands and estuarine resources. Localized clearings grew into agricultural hamlets, and the crops grown expanded to include beans, squash, and some tobacco. The villages were probably abandoned every 10-12 years due to exhaustion of the soil and a lack of firewood. Much of the forest in areas near Native American settlements lacked undergrowth which would indicate regular burning. A "barrens" that existed at the headwaters of Winters Run is believed to be the result of periodic burning by the Native Americans (Custer 1984 and 1986; Frye 1986; Gardner et al. 1988; Potter 1993). In 1608 Captain John Smith described much of the western shore of the upper Chesapeake (including the Bush River) as consisting of extensive woods with virtually no visible sign of humans (Barbour 1964).

European settlement began with the first land patents in the Bush River area in 1658; by 1700 the entire shoreline was patented (Wright 1967). In 1661 Old Baltimore Towne was established as the county seat of Baltimore downriver on the Bush River. In 1691, the town was abandoned and the county seat was relocated in Joppa Towne along the Gunpowder River, after siltation of the harbor and trading distance became a problem. By 1700 isolated tobacco farms were situated along the estuary for easy transportation. Because tobacco planting (clearing-crop-abandonment-succession) was a low impact crop, not much soil was erodible. By 1730 settlement began to expand away from the shore and into the Piedmont uplands. Land under cultivation is estimated to have been between 5% and 20% in the upper Chesapeake Bay region (Jacobson and Coleman 1986; Davis 1985; Karinen 1959).

During the next 50 years large plantations added corn, oats and wheat to the tobacco crops (Gardner et al. 1988). Land under cultivation increased to 50% between 1770 and 1800 (Davis 1985). Deforestation in the watershed began to accelerate in the early 18th Century, so that by 1730 forest cover had declined to between 95 and 80%, by 1800 to 80 to 50%, by 1850 to 50 to 40%, and by 1900 to 40 to 20%. Thus the period that witnessed the most rapid and extensive loss of forest was 1730-1800 (30%). Erosion from increasing land clearance, agriculture and development produced increased sedimentation in nearby ports and caused the abandonment of Joppa Towne as the county seat in 1768. The Baltimore County Seat was moved to the present location of Baltimore along the Patapsco River. Eutrophic conditions in Chesapeake Bay became established for the first time in at least 2,500 years when increased nitrogen and planktonic diatoms and a decline in benthic diatoms and overall diatom diversity occurred during the mid-18th century (Cooper and Brush 1993).

The 19th century brought a switch from low intensity tobacco farming to grain agriculture when farming became mechanized. From 1800 to 1850 an increase in more land under cultivation, increased fertilizer use and deep plough farming produced increased upland erosion, intensifying eutrophication and sedimentation in the estuary (Brush 1992; Earle 1992). In an 1836 map, OPC is shown as an open estuary surrounded by farmland with only six houses located within a kilometer (0.62 miles) of the Creek (Hazelhurst 1836). At this time the Pennsylvania Railroad was under construction downriver across the Bush River (near the present Route 40).

The period from 1850 to 1910 was marked by mining of quartz and iron ore, cannery construction and distribution, major railroad construction, further deforestation on marginal land with steep slopes, and the most important period of sedimentation in OPC (Hilgartner and Brush 2006; Earle 1992; Frye 1986). Iron ore was mined in nearby Abingdon in the 1880s, a town which also served Otter Point Landing, an important shipping port (Frye 1986). By 1890 many large farms in the area had their own canneries of shoe-peg corn (Gardner et al. 1988). The Baltimore and Ohio Railroad was built paralleling present-day Route 40 between 1880 and 1885. Forest cover dropped to 20% by 1900 in Harford County. Jacobson and Coleman (1986) calculated that sedimentation in the Piedmont counties, including Harford County, rose sharply throughout the 1800s, peaking around 1880. Hilgartner and Brush (2006) found that the period of highest sedimentation rates occurred throughout the OPC estuary between 1840 and 1880, causing a shift from open water to low marsh, and in some places high marsh and forest. The wetland forested area adjacent to the Perry Avenue Pumping Station established in 1850 (Hilgartner and Brush 2006). Today this 160 year old riparian forest contains giant sycamores and river birches with a series of nature trails threaded throughout.

After 1910, an increasing number of farms were abandoned, resulting in greater forest cover over subsequent years. In 1917, much of the area downriver from OPC was purchased by the U.S. Army for Edgewood Arsenal and Aberdeen Proving Ground. From that time on, agriculture and residential development ceased and much of the 18,000 hectare (44,479 acres) area returned to forest.

Afforestation increased to 35% between 1910 and 1950 as farms were abandoned, particularly after 1935, in part the result of the Great Depression (Brush 1989; Jacobson and Coleman 1986). This also represented an important period of road and dam construction within the Winters Run watershed. Route 40 was constructed in 1938, with a 2.5 m embankment along the north end of OPC. Atkisson Dam and the much smaller Van Bibber Dam downstream were built in the 1940s during World War II. Evidence from sediment cores shows that a large amount of sediment deposition into OPC occurred prior to 1950, attributable to these construction projects (Hilgartner and Brush 2006). Construction has been shown to cause sharp spikes in sediment input due to exposed erosional surfaces (Groffman et al. 2003; Wolman 1967). The OPC wetland underwent a shift again to greater marshland and more forested area, with two main deltaic channels, reaching much of its present day geomorphology. No significant expansion of marsh has occurred since 1950 based on sediment cores and aerial photos, indicating that the dams have served as a sediment trap since 1950.

The period from 1950 to the present (2010) has been one marked by housing and residential developments and an explosion in population growth. Population growth in Harford County (which includes the entire Winters Run and Bush River watersheds) increased slowly, from 12,700 people in 1775 to 35,000 around 1925. By 1750 the Native Americans were absent from the present Harford County. Population growth accelerated after 1925; by 2007 the population had reached 238,960 (Source: U.S. Census Bureau, 2005-2007 American Community Survey; retrieved April 2009 from http://factfinder.census.gov/home/saff/main.html?_lang=en).

Improvements in transportation, including the construction of Interstate 95 and the implementation of State owned commuter rail service increase the feasibility of working in the city of Baltimore and living near the Reserve component. All these factors are tending to increase the trend of urbanization within the OPC watershed. In addition, the implementation of the 2005-approved Base Realignment and Closure (BRAC), which calls for the repositioning of thousands of overseas U.S. troops and stateside base closings or adjustments, will directly affect Harford County development. An approximate number of 4,400 of military, government civilian, and civilian contractor staff are expected to be relocated to Harford County area (Flakes 2007).

Edgewood Meadows, a residential development along the southwestern shore of OPC was built during the 1960s. In 1976 the Harbor Oaks subdivision along the southeast shore of OPC was approved and expanded. During the mid-1980s through the mid 1990s the Westshore townhouse development was completed in stages along the north edge of the wetland. Sediment trap ponds were constructed between the townhouses and the wetland. Within the wetland itself, sewage lagoons were excavated between 1966 and 1968 as an interim sewage treatment measure while the Perry Avenue, Winters Run and Bill Bass Pumping Stations were being constructed. The ponds were abandoned in 1971 and were inundated with sediment by flooding from Hurricane Agnes in 1972. Today the lagoons are mostly marsh with a ring-like channel around each periphery. Route 24 was built at the southwest edge of the wetland in 1971, creating an 8.5 m high embankment. Flooding from Hurricane Agnes also converted the forested wetland adjacent to the road into a marsh which has remained to the present (Hilgartner and Brush 2006).

The property comprising the Melvin G. Bosley Conservancy was purchased by Melvin Bosley, a local real estate developer and donated to the Harford County Chapter of the Isaak Walton League to serve as habitat for the preservation of waterfowl and fish for sport. The area is now bordered by a trailer park and housing developments on both sides of the riparian forest. There is little buffer between the residential area and the Reserve. Although perimeter boundary signs have been installed, human activity on the boundary remains high, and there has not been universal acceptance of the need for access control on the part of the adjoining residents. Through the CBNERR-MD partnership among the National Oceanic and Atmospheric Administration, Maryland Department of Natural Resources, and Harford County, Leight Park was established as a county park around 1990. The park provides nature and environmental education of the river and its inhabitants. The Anita C. Leight Estuary Center was built in October of 1996 with NOAA and county funding.

2.2.1 Archaeological resources

Harford County is one of the longest-settled areas in eastern North America. Within the County there are 5,000-year-old archaeological sites from the era of the Susquehannocks, early English colonial cabins, Palladian style mansions, two of the few remaining Freedmen's Bureau schools, houses built by French emigres fleeing revolution in Europe and the Caribbean, and some of the country's earliest and finest Gothic Revival Churches (Harford County 1998). Archaeological remains in the area show the presence of aboriginal people as early as 9,500 years ago in the Winters Run-Otter Creek watershed (Frye 1986). Furthermore, the Maryland Historical Trust indicates that at least one archaeological site exists in the OPC component. Historically, it is the site of Chilberry Hall, the birthplace of Maryland Governor William Paca. It is likely that additional sites may be located here; however, an archaeological survey has not been conducted.

2.3 ENVIRONMENTAL SETTING

The OPC component of the Reserve forms part of the OPC subwatershed. This subwatershed is 163 km^2 (63 $mi.^2$) in size and is one of three subwatersheds of the Bush River, along with Bush Creek and Church Creek subwatersheds. In the area draining directly into the Bush River, the OPC subwatershed contains two main drainage areas HaHa Branch and Winters Run, which at the same time drain other sub-drainage areas including Mountain Branch, Plumtree Run, etc. (Figure 2.3.1).

The Bush River is a very productive, complex, and dynamic system, and its productivity to a considerable extent depends on the health of the marshes. Unfortunately, all three subwatersheds in the Bush River have been listed by the State of Maryland as impaired waters and the watershed as a whole is considered a priority for restoration (Maryland Department of Natural Resources and Harford County 2002).

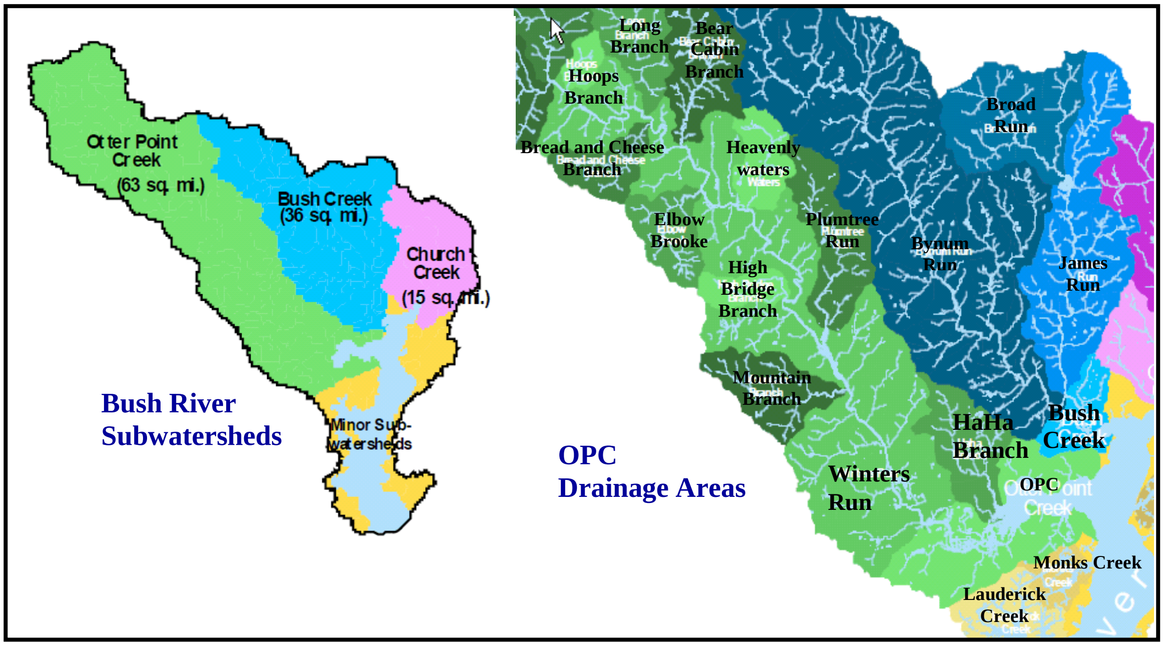
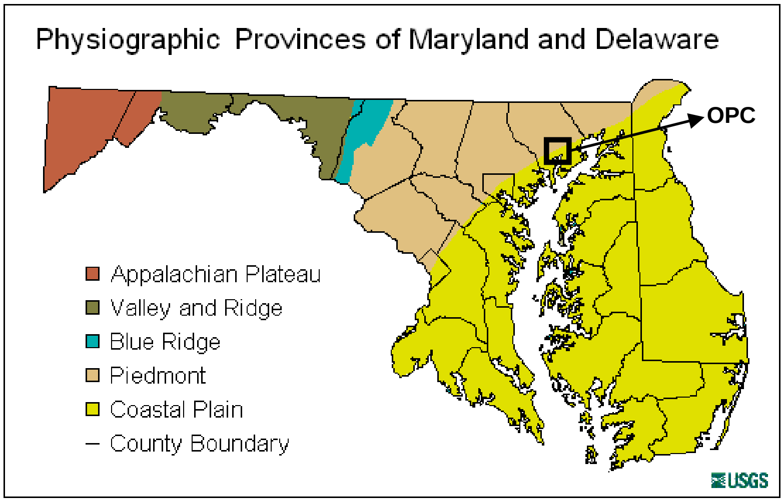


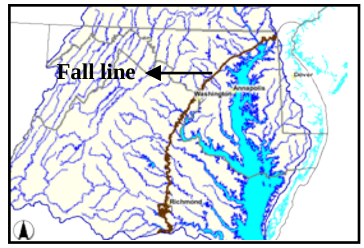
Figure 2.3.1 Representation of Bush River subwatersheds and the main drainage areas of the OPC subwatershed: Winters Run and HaHa Branch. Source: Harford County Department of Public Works (2010).

2.3.1 Geologic History

The Bush River watershed lies entirely in Harford County, Maryland and drains 303 km^2 (117 mi.^{2}) of land. OPC lies at the base of the Piedmont (fall line), within the Coastal Plain (Figure 2.3.2), a province underlain by Quaternary lowland gravel, sand, silt and clay deposits (up to one million years B.P. – before present), with some unconsolidated Cretaceous gravel and sand on the uplands (63 to 135 million years B.P.; Cleaves et al. 1968). Most of the watershed above the fall line is within the Piedmont province and underlain by soils weathered from Precambrian and early Paleozoic schist, granite, gneiss, gabbro, and serpentenite crystalline rocks.



Source: U.S. Geological Survey 2010



Source: U.S. Environmental Protection Agency, Chesapeake Bay Program

Figure 2.3.2 Map showing the location of OPC in relation to Maryland physiographic provinces. Figure on the right shows the location of the fall line (boundary separating the soft Coastal Plain from the hard Piedmont). Stream and river reaches above the fall line are free-flowing; below the fall line they are tidal.

The Precambrian and Paleozoic geologic history of the Piedmont of north central Maryland and southeastern Pennsylvania is complex, spanning a period of 1.1 billion years, and has been described by Schmidt (1993) and Van Diver (1990) and more recently by Pyle et al. (2006). The Piedmont landscape evolution of Maryland from the Permian to Recent has been summarized by Cleaves (1989) and Costa and Cleaves (1984).

Highlights of this history are presented here. The basement rock known as Baltimore Gneiss began as a granite intrusion into the former smaller North American continent during a mountain building period called the Grenville Orogeny. Uranium-lead dating from zircon crystals in the gneiss has produced dates ranging from 1.1 billion years in Maryland to 1.075 billion years in southeastern Pennsylvania. An unconformity of approximately 600 million years is found between this lower gneiss and the overlying Setters Formation of the Glen Arm Series. This represents an incredibly long erosional period. The Setters Formation is predominantly quartzite and gneissic, originally sediments laid down in shallow off-shore environments in the Cambrian Period around 540 million years ago. Overlying the Setters is Cockeysville Marble, a dolomitic, metamorphosed limestone that indicates a tropical carbonate environment around 500 million years ago. Overlying the marble is the Loch Raven Schist (formerly known as the Wissahickon Schist). A Uranium-lead date of 480 million years places this formation in the early Ordovician. The environment indicated by these metamorphosed sediments is a deep marine deposit in a forearc basin. The forearc is a depression in the sea floor located between a subduction zone and a volcanic arc. It was about this time, 490-480 million years ago, when metamorphism of the Baltimore Mafic Complex, which includes serpentinite, was produced as parts of oceanic plate were obducted onto the edge of a converging continental plate and volcanic island arc complex. This period of metamorphism is known as the Taconic Orogeny, the first of three mountain building periods in the Paleozoic of Maryland.

A second mountain building period, the Acadian Orogeny, occurred during the mid to late Devonian about 350 million years ago. During this orogeny, a mountain range and further metamorphism resulted from the collision of the European plate and the Laurentian plate in New England and Canada to the north of Maryland. Potassium-argon dating from biotite in Baltimore Gneiss provides dates of 360-350 million years ago when recrystallization occurred. Some Argon/Argon dates from the schist show that some metamorphism occurred as early as 410 million years ago, so this suggests that the Loch Raven Schist formed between 410 and 360 million years ago, and is consistent with the second period of metamorphism in the Baltimore gneiss.

The third and final mountain building period was the Alleghenian Orogeny, which occurred during the late Paleozoic from 300 to 250 million years ago. Northeastern Africa (Gondwana) merged with eastern North America (Laurentia) producing Pangaea and the formation of mountains perhaps as high as the modern Himalayas. This placed Maryland in a mountain range in the middle of an enormous continent. By late Triassic times the plates separated, which continued during the Jurassic with much erosion. A period of major erosion in the early Cretaceous began producing much of what we see today on the western shore of Chesapeake Bay. The early Cretaceous erosional period was most likely enhanced by tectonic uplift and erosion of the Piedmont. These deposits are non-marine fluvial and deltaic sediments. Numerous fossils of plants and reptiles have been recovered from similar sediments along the Fall Line in Maryland.

Overlying the Cretaceous sands are Quaternary lowland sand, silt and clay, particularly along rivers. The Quaternary sediments were primarily deposited during peri-glacial and Holocene erosional periods. The Chesapeake Bay began to flood the old Susquehanna River valley about 10,000 to 8,000 years ago as Wisconsin glacial ice sheets melted and retreated northward, producing sea level rise. The rate of sea level rise was too rapid for marsh establishment until roughly 3,000 years ago when the rate of sea level rise slowed and the first tidal marshes began to appear. It was about this time when the current dimension of the Bay was established and it had reached its northernmost point. From 2,000 years until about 300 years ago the Bay appears to have been a stable estuary with abundant flora and fauna. A pulse of high sedimentation beginning 350 years ago from deforestation and colonial expansion produced steep river banks and expanded marsh and riparian forest habitats into the estuary, further expanding marshland, particularly along the western shore (Hilgartner and Brush 2006, Brush and Hilgartner 2000, Khan and Brush 1994, Froomer 1980).

The Bush River and its tributary OPC were formed a little over 3,000 years B.P. by the melting of the glaciers and the resulting rise in sea level. Currently, sea level continues to rise locally at 3.17 mm yr^{-1} (± 0.13 mm yr^{-1}) reflecting a combination of regional land subsidence and global sea level rise (Marcus and Kearney 1991, Kearney and Stevenson 1991). Local land subsidence may be caused by the compaction of coastal plain sediments due to ground water withdrawal or down warping of the strata adjacent to the Chesapeake Bay. Down warping yields the redistribution of sediment from the upland land areas to the subtidal locations of the Chesapeake. Rising sea levels acting on the unconsolidated sediments produce significant shore line erosion and redisposition of sediment continuing the process until ultimately the Chesapeake fills in. OPC, like most other tributaries below the fall line, is getting shallower with time. Although this process has been occurring since the Chesapeake was formed, deforestation for agriculture and housing development are also responsible for the accelerated deposition of soil in shallow waters. Shoaling of navigable waters is a problem of historical record in many places within the Chesapeake. The most spectacular example of this is the more than two mile retreat of the shoreline from the former port of Joppatowne (located on the adjacent Gunpowder River) and its subsequent replacement by Baltimore as the principal port in Maryland.

The soil series identified on the western portion of OPC include Tidal marsh, Swamp, Hatboro silt loam, and Codorus silt loam. Tidal marsh soils dominate the core area, ranging from sand to clay. This is highly erodible soil; water channels have formed incised banks and would tend to undercut shoreline trees. Stream channels are tidally influenced with currents reversing in some of the cross channels with changes in tide. The high erodibility of the soils both in and upstream of the marsh is the driving force in the expansion of the marsh area. Shallow cores taken from the outer edge of the marsh show very little accumulation of the organic, fibrous plant material, marsh peat, which characterizes the higher salinity marshes. This difference in the soils causes a difference in the vegetation of the site as well.

Swamp soils, which occur near the old sewage oxidation ponds, may contain high concentrations of sulfur compounds and are characterized by freshwater submersion nearly all the time. Hatboro and Codorus silt loam are characteristic of the flood plain. These soils formed in recent alluvium which originated in areas of crystalline rocks inland of the Coastal Plain.

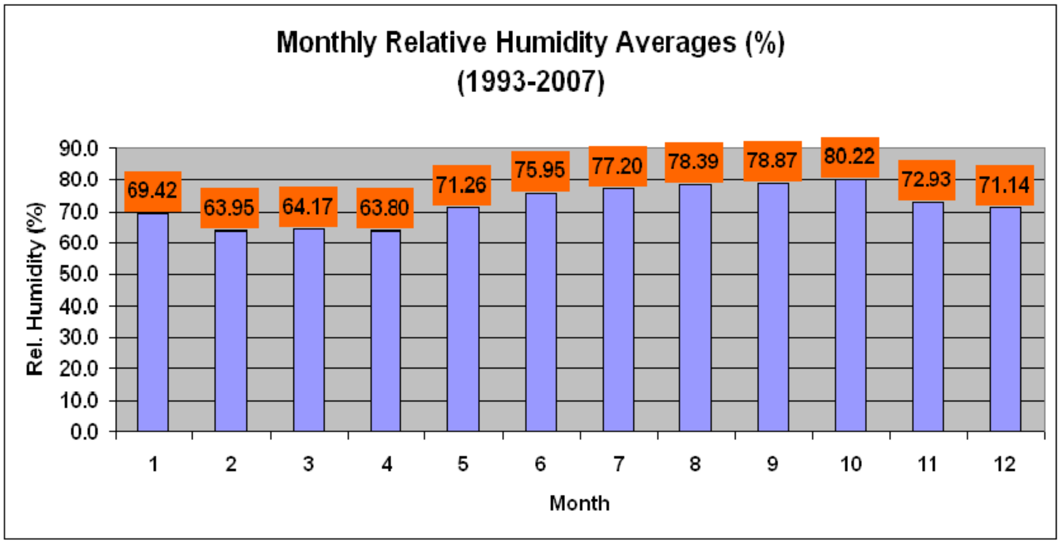
The Leight Park property, located at the eastern portion of the site, contains several soil series. Beltsville silt loam in moderate (5% to 10%) slopes is a moderately well drained soil found on uplands of the Coastal Plain.

2.3.2 Climate and Weather

The climate around OPC is humid and continental. The weather is determined primarily by a series of fronts moving generally from the northwest bringing changes in surface winds and humidity. Weather information presented in the following sections is based on data collected from two weather stations, one located in the Aberdeen Proving Grounds (39°26'N / 76°05'W) and the other one located at OPC within the Reserve (39° 27.047' N / 76° 16.474' W). The Aberdeen station has operated since 1918, while the station at OPC started operations in 2004. Due to limited data accessibility from the Aberdeen Proving Ground station only data from 1993-2007 is presented here.

2.3.2.1 Weather annual patterns

Humidity within the OPC area is generally high throughout the year, ranging between 63% - 81%, with the months between June and October as the most humid (Figure 2.3.3).

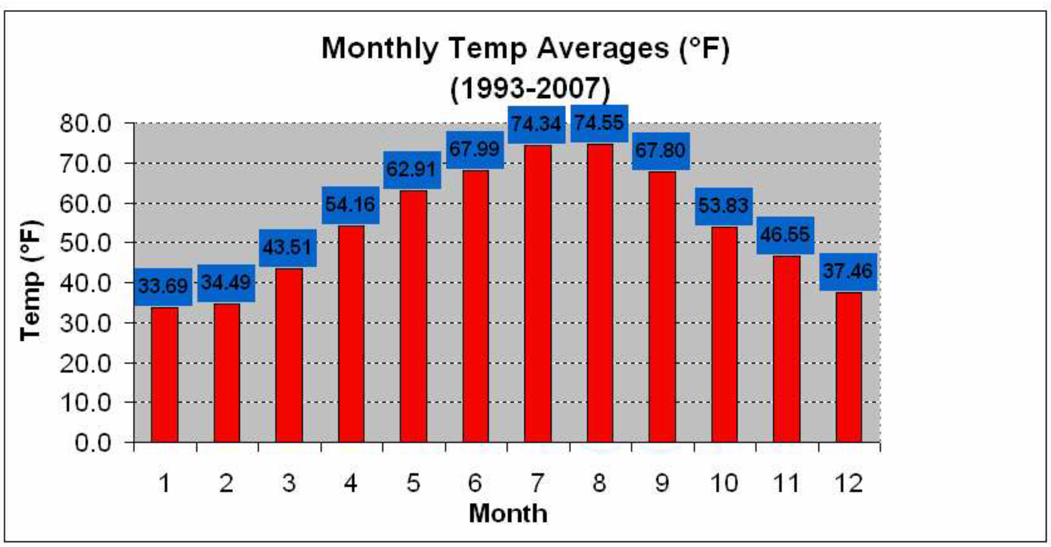


Graph Notation for Months (1=JAN, 2=FEB, etc)

Note: 24 hour data used to compile this graph.

Figure 2.3.3 Monthly relative humidity averages (%) for the period 1993-2007. Data source: Aberdeen Proving Grounds Weather Station. Data source: Aberdeen Proving Grounds Weather Station.

The average annual air temperature is 12 °C (54 °F) with average high temperatures in July and August of about 24 °C (74 °F) and average lows in January of 1 °C (34 °F); (Figure 2.3.4).



Graph Notation for Months (1=JAN, 2=FEB, etc)

Note: 24 hour data used to compile this graph.

Figure 2.3.4 Monthly air temperature averages (°F) for the period 1993-2007. Data source: Aberdeen Proving Grounds Weather Station.

The water temperature in the Bush River and OPC may range from a summer high of 28 °C (82 °F) to a winter low of 2 °C (36 °F). Often, during the winter time, water temperature can drop to 0 °C (32 °F) and stay for a few days, which results in the formation of a layer of thin ice that covers a large part of the OPC embayment (Figure 2.3.5).

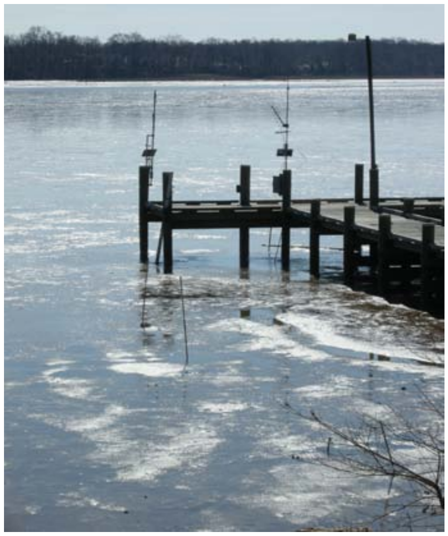
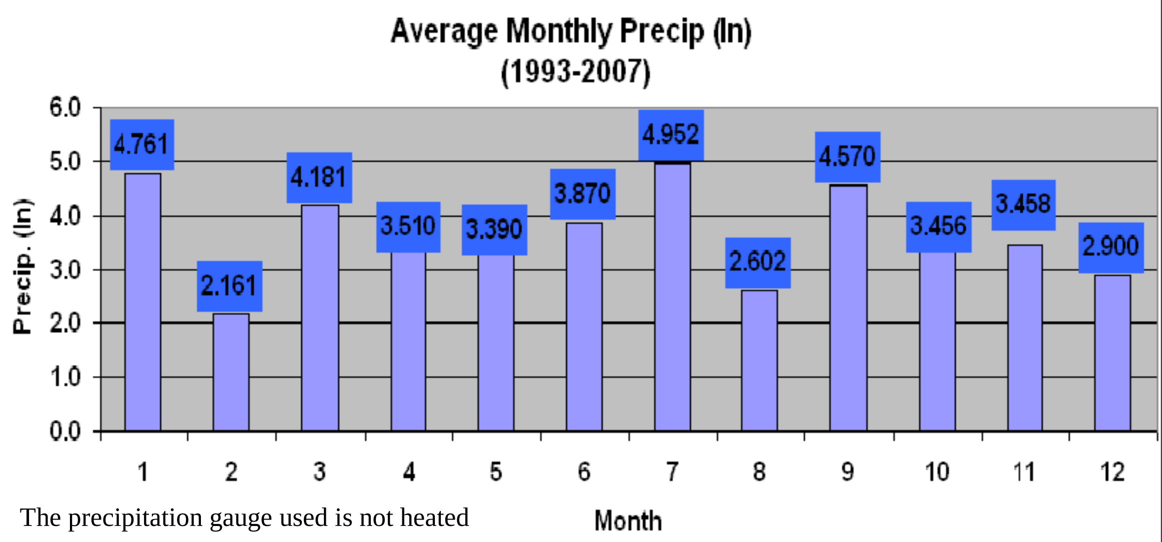


Photo credit: P.Delgado

Figure 2.3.5 A thin layer of ice forms during low water temperatures at OPC. Also shown is the location of the CBNERR-MD weather station and the continuous water quality monitoring station.

The annual precipitation can be quite variable but is usually fairly evenly distributed throughout the year (Figure 2.3.6). The monthly average precipitation ranges 5.5 – 12.6 cm (2.161 – 4.952 in.). The late summer is frequently dryer than the rest of the year, but there is no month which is typically devoid of precipitation. The annual average precipitation is 9.3 cm yr^{-1} (3.651 in yr^{-1}) and the total annual precipitation is 111 cm (43.811 in.).



The precipitation gauge used is not heated

Graph Notation for Months (1=JAN, 2=FEB, etc)

Note: 24 hour data used to compile this graph.

Figure 2.3.6 Monthly average precipitation (inches) for the period 1993-2007. Data source: Aberdeen Proving Grounds Weather Station.

As part of the weather component, wind is an important factor determining water level conditions in OPC (see section 2.3.4. Hydrology). Because of the characteristic shallow conditions of the OPC environment, strong winds that may result from occasional storms or hurricanes can lead to significant changes on water levels, ranging from complete depletion of water to water levels above normal conditions. For example, in 2003 strong winds associated with Hurricane Isabel resulted in extremely high tides. Water level remained high for about 7-10 days following the storm, so much that there was not a distinction between low and high tides. During that period, water level was approximately five feet (1.5 m) above normal high tide.

An annual analysis of wind direction and speed for the OPC area indicate a dominance of winds blowing from the west with speeds that range between 0.5 to 8.8 m s^{-1} (1.1 to 19.7 mph); (Figure 2.3.7).

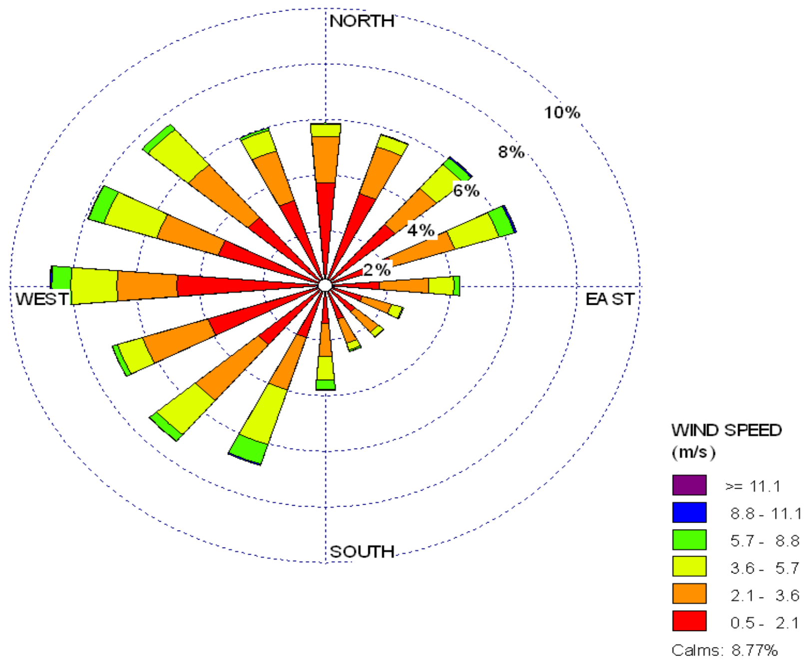


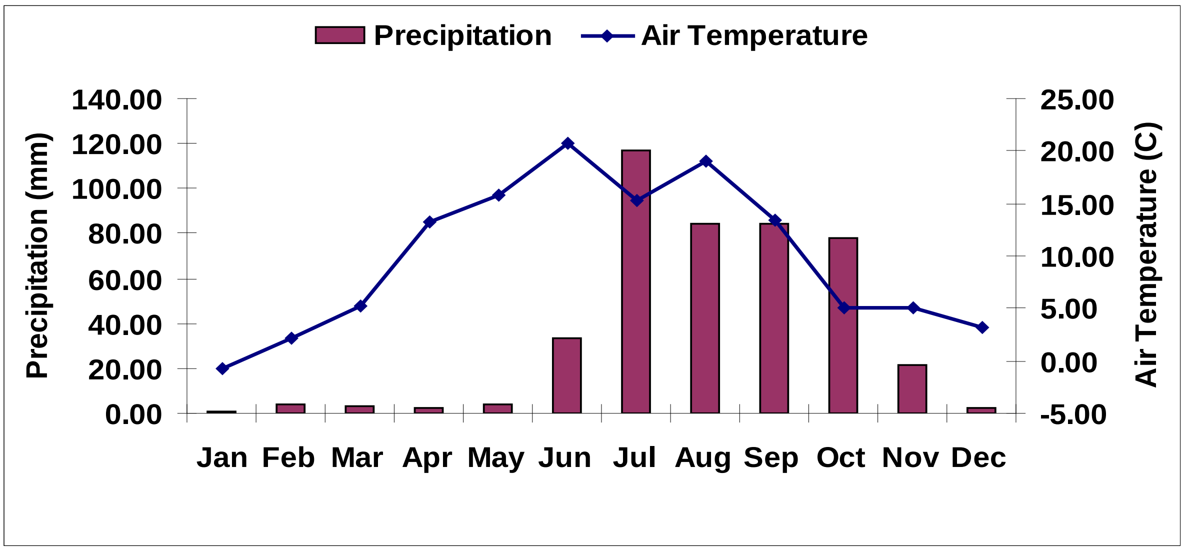
Figure 2.3.7 Graphical representation (wind rose) of yearly average wind direction and speed for the period 1993-2007. Bars represent 16 wind directions, and each bar is divided into wind speeds (color coding). As the percentage of time that the winds blows from one of the 16 directions, the bar representing the wind speed gets larger both in length and width. Data source: Aberdeen Proving Grounds Weather Station.

Other weather phenomena that may affect OPC conditions are related to El Niño or La Niña events. During the winter of 1994–1995 an El Niño event resulted in a significantly warmer than normal condition in this area and abnormally low snow cover, which lead to one of the five warmest periods in the 100-year record for Maryland. These warm conditions continued through the summer in association with a severe drought. A drastic change from a warm El Niño to a cold La Niña occurred during the winter of 1995–1996 and OPC was completely frozen by the beginning of December 1995. In January 1996, a blizzard dropped over 508 mm (20 in.) of snow in the region and OPC remained frozen until April (Pasternack and Hinnov 2003).

During October 2004, one of CBNERR-MD's meteorological stations was installed at the OPC site. Data from this station is collected every 15 minutes resulting in the output of fifteen minute, hourly, and daily averages, maximums, and minimums. The data from this station is currently being archived by CBNERR-MD, but will soon be accessible online through the Maryland Department of Natural Resources' eyesonthebay website (http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm).

The OPC weather station is located within the OPC embayment surrounded by a tree line (Figure 2.3.5). These somewhat enclosed conditions plus inherit spatial weather variability may explain differences between the data collected by this station and other local weather stations within the area. Data from the OPC weather station is very valuable because it captures the local weather conditions around OPC, particularly the marsh environment, where a significant part of the CBNERR-MD research is conducted.

A general analysis of the short-term OPC weather station's data shows a similar temperature pattern to that given by the longer term data of the Aberdeen Proving Grounds Weather station (Figure 2.3.8). The monthly average temperature ranged between approximately -1 to 21˚C, with the highest temperatures between the summer months (June-August) and the lowest during the winter months (December-February).



	J	F	M	A	M	J	J	A	S	O	N	D
Temp. (°C)	-0.69	2.19	5.22	13.17	15.79	20.79	15.30	19.06	13.40	5.13	5.07	3.14
Precip. (mm)	1.01	4.13	3.02	2.47	4.29	33.11	116.93	83.96	84.03	77.56	21.36	2.12

Note: OPC weather station data has been collected for 2004-2006 and 2008-present. Due to maintenance and recalibration this weather station was not operating in 2007 and beginning of 2009.

Figure 2.3.8. Monthly average temperature and precipitation; OPC weather station. Data used: 2004-2006 and 2008.

The precipitation pattern shows two main distributions, lower precipitation between the months of November and May and higher precipitation between June and October. The monthly average precipitation ranged from 0.1 cm in January to 11.7 cm in July (Figure 2.3.8).

2.3.3 Estuarine Geomorphology, Soils, and Sedimentary Processes

Tidal freshwater wetlands (TFW) as those characteristic of the OPC component lie at the interface between upland watersheds and tidal rivers along the Atlantic and Gulf coasts of eastern United States. Paleoecological and geomorphological reconstructions in these environments have shown that over the past 350 years human impact, particularly sediment efflux from deforestation and hydrologic change through channelization, have been important factors in initiating TFW and estuarine marsh and wetland forest development in the central Chesapeake Bay region (Gottschalk 1945, Froomer 1980, Khan and Brush 1994), Delaware River (Orson et al. 1992), and New York (Heusser et al. 1975, Pederson et al. 2005). In some Delaware River TFWs, their development was generated by natural disturbance such as changing flooding regimes from sea level rise (Carmichael 1980, Orson et al. 1992), while in two other sites dominant species have persisted for more than one thousand years with no change (Hilgartner unpublished data).

OPC is a tidal freshwater estuary containing a series of distributary channels flowing into the Bush River. The areal extent of the OPC is approximately 1.39 km^2 (0.54 $mi.^2$). Winters Run, the main river flowing into OPC, drains a watershed of 150 km^2 (58 $mi.^2$). Geomorphic and hydrometerological analyses of modern sedimentation rates and water level controls in the wetland are reported in Pasternack and Brush (1998, 2001), Pasternack et al. (2000), and Pasternack and Hinnov (2003). Hilgartner and Brush (2006) report on the environmental history and habitat development of the OPC wetland. Pasternack et al. (2001) propose a diffusion model reflecting historic depositional patterns of delta progradation and land use history.

The following 2000-year site history of OPC based on the paleoecological record is from Hilgartner and Brush (2006). The aquatic macrophyte habitat in the Bush River/OPC estuarine basin remained relatively stable for 15 centuries, from the second century A.D. to 1700 A.D. A prehistoric and undisturbed forested watershed, acting as a storm buffer in flood and erosion control, released sediment into the estuary at a mean rate of 0.05 cm/yr (0.02 in. yr^{-1}) during this extended period. While major storms have occurred with regular frequency during this time, at least during the past 700 years (Donnelly et. al. 2001a, 2001b), no stratigraphic evidence of storms appears in sediments deposited prior to European settlement. This storm buffer effect of forested watersheds is well-documented elsewhere from recent and long-term watershed studies as well as from geomorphologic reconstructions (Bormann et al. 1974, Jacobson and Coleman 1986, Freedman 1995, Goudie 2000).

The absence of any shift in habitat and dominant species in 1500 years indicates that autochthonous or biological factors, as well as Medieval and Little Ice Age climate change, are not important in initiating habitat change during a time spanning 1000-2000 years. Habitat change proceeded only after the sedimentation rate increased during the 18^{th} century. This supports other studies that show that rapid accretion of infilling silt, sand, and clay from anthropogenic disturbance is the primary factor forcing major changes in species assemblages in coastal wetlands (Khan and Brush 1994, Cole 1994).

Beginning in the early 1700s sedimentation rates increased sharply. The initial influx of sediment was synchronous with European settlement and land clearance, as populations migrated into and began to cultivate the steeper slopes of the Piedmont between 1730 and 1780. Erosion steadily increased as forests were cleared and agriculture became more extensive. The subtidal habitat that had persisted for centuries tolerated this initial phase of sediment increase with shifts in species abundances as sedimentation rates increased from 0.05 cm yr^{-1} (0.02 in. yr^{-1}) to less than 0.60 cm yr^{-1}(0.2 in. yr^{-1}). However, aquatic macrophytes disappeared when a mean sedimentation rate of 0.60 cm yr^{-1} (0.2 in. yr^{-1}) had been attained. This rate appeared to be a critical threshold, because habitat change proceeded as rates continued to rise above 0.60 cm yr^{-1} (0.2 in. yr^{-1}) during the 19^{th} century and the first half of the 20^{th} century.

The period of peak accretion rates ranging from 3.9 cm yr^{-1} (1.5 in. $^{-1}$) to an exceptional 48.0 cm yr^{-1} (18.9 in.$^{-1}$) occurred between 1840 and 1880. During this period forest cover in the watershed was reduced from 40% to 20% and new settlement occurred on steep, marginal slopes that had been inaccessible or undesirable previously (Earle 1992). Increased storm water runoff on a deforested landscape comprised of steep, marginal slopes would certainly have produced increased erosion rates and sediment deposition in the estuary. Hydrographic data show that flow rates following storms in a deforested or urbanized watershed can be 5-10 times greater than flow rates from a forested watershed, and that the rate of sediment yield appears to double for every 20% loss in forest cover (Goudie 2000).

Stratigraphic evidence of storms after 1700 A.D. is present in the form of thin laterally accreted layers of sand, muscovite and allochthonous seed and leaf fragments. This occurred during the mid-1800s, when four major storms impacted the region and habitat change in the estuary was most extensive. During this period the subtidal habitat disappeared at all sites while low marsh and riparian forest expanded. Between 1750 and 1950 habitat communities shifted throughout the estuary. Habitats changed at five coring sites from wetter to drier, one changed from drier to wetter, and one did not change. The trajectory of temporal change reflects the physical position of modern habitats relative to subtidal and channel margins; i.e. from the most flooded (subtidal) to least flooded (riparian forest).

However, the sequence, rate of change, and species composition at each coring site varied considerably, demonstrating the influence of local site characteristics on spatial variability within and between habitats. The most rapid set of changes occurred at the upper wetland site; subtidal habitat shifted to middle marsh, shrub marsh and riparian forest within 75 years "skipping over" the low marsh and high marsh sequences. This site received the deepest post-settlement deposit of 240 cm (94.5 in.). The lower wetland sites receiving less deposition experienced roughly equal levels of post-settlement deposits of 165 cm (65 in.) and shifted more gradually from subtidal to marsh habitats. In addition to differential sediment deposition between sites, minor changes in species composition could have been caused by local, physical differences in hydrology and nutrients (Gosselink and Turner 1978, Mitsch and Gosselink 2000), or biological factors including herbivory, competition, seed dispersal, colonization, seed bank dynamics or channelization by beavers (Connell and Slatyer 1977, van der Valk 1981, Simpson et al 1983, Huston and Smith 1987, Leck 1989, Crawley 1997, Pasternack et al. 2000).

The data demonstrate that marsh and forest habitat development did not occur gradually over the past 300 years but proceeded in alternating periods of stasis bounded by periods of change. The periods of change or pulses were in response to high yields of sediment input and the pulse period varied somewhat with each core depending on its proximity to the watershed or distributary channel. New habitats established equilibrium within a new elevation and range of sedimentation rates. This stasis-pulse-stasis model is similar to the equilibrium-disequilibrium model derived from paleoecological studies of habitat development in kettle-hole peatlands in Wisconsin and Ontario (Winkler 1988, Campbell et al. 1997). In these instances habitat change is produced by dramatic shifts in hydrology from climate change spanning centuries. By contrast, habitat response at OPC occurred within decades as a result of changes in sedimentation rates resulting from human induced soil erosion.

No significant change in wetland configuration or broad habitat change has occurred since the early 1950s. The absence of any broad change follows closely behind the completion of the construction of Route 40 adjacent to the north end of the estuary in 1938, and construction of the Atkisson and Van Bibber Dams in 1944-45. The Atkisson Dam traps sediment supplied from the upper two thirds of the watershed. Thus while high sedimentation rates during dam and road construction appear to have contributed to habitat change before 1950; a substantially reduced sediment load reached the estuary after 1950. Low sediment yields, often less than quantities produced during the 19^{th} century, can follow a tenfold increase in sediment yields during construction (Wolman 1967, Groffman et al. 2003). The coincidence of reduced sediment yields from the watershed since 1950 (mean rate of 0.52 cm yr^{-1} or 0.2 in. yr^{-1}) with the reduction or cessation of delta progradation and habitat change in the estuary, further identifies watershed disturbance as the primary influence on wetland habitat development and configuration.

A conceptual model is proposed to describe the history of disturbance and habitat change in an upper estuary, where there is a potential for a shift to a freshwater tidal wetland. Since virtually the entire Chesapeake Bay watershed has been deforested in the 380 years since European settlement (Brush 1992), and since much of the western shore of the Bay adjoins the steep fall line, it is believed that this model describes the development of freshwater tidal wetlands in most sub-estuaries along the western shore of the Chesapeake Bay. Furthermore, the model may have broader application and describe the development of any TFW that forms the basin of a forested watershed with steep slope topography, since watershed slope is an important factor in sediment supply (Goudie 2000, Pastenack et al. 2001). Refinement of this model could be accomplished through further study of the effect of watershed slope, ratio of watershed area to basin area, dominant vegetation, and varying human and natural disturbance regimes.

The formation and evolution of the marsh to its present configuration is documented in the historical record from maps and aerial photography. Because OPC is dominated by the flow from Winters Run, and to a lesser extent HaHa Branch, any activity in the watershed influences what happens in the estuary. Sediment, nutrient loads, and water level fluctuations are all determined by past and present activities in the watershed (Copeland et al. 1983).

Sedimentation has caused and continues to cause an increase in the total Bush River marsh acreage. A comparison of old maps from the 1800's with more recent ones shows a gradual increase in the above water marsh area. A delta has formed, and continues to form, at the mouth of OPC (Harford County Planning and Zoning 1984). In the 1800's, HaHa Branch entered OPC nearly midway between Winters Run and the Otter Point Landing with very little marsh present. However, by 1950, the OPC marsh expanded to nearly cutting off the embayment where HaHa Branch enters OPC. By the late 1950's, the tidal channels of OPC began to extend beyond the HaHa embayment, cutting it off from direct connection with the river. The tidal channels are developing distinct levees of higher elevation from the surrounding marsh. The marsh edge appears to continue to expand outward and may in time fill the entire open water portion within the reserve boundaries.

2.3.4 Hydrology

In a simplistic way, the ecology of a tidal freshwater wetland (i.e., species distribution, composition, plant density, etc.) is mainly governed by its hydrological regime which drives water level changes and the exchange of materials as a function of daily, monthly, and seasonal processes including river discharge, tides, winds, as well as unpredictable events such as storms and hurricanes.

2.3.4.1 River discharge

The tidal freshwater system at OPC is characterized by the input/exchange of freshwater from three main tributaries and their watersheds: OPC (144 square kilometer or 55.6 square mile drainage area), Winters Run (90 km^2 or 34.7 $mi.^2$ drainage area) above the head tide, and HaHa Branch; all of which feed into the Bush River Basin (Figure 2.3.1). Within the larger scale, the Bush River and the Chesapeake Bay also influence the hydrology at OPC mainly during strong winds events which push water in or out of system (see section 2.3.4.3: Winds, storms and hurricanes).

The United States Geological Survey (USGS) gage stations located in Winters Run, near Benson Road, MD and OPC near Edgewood, MD have been operating since 1967 and 2004, respectively. Records from these stations show that the highest daily mean discharge value for Winters Run (85 $m^3 s^{-1}$ or 3,000 $ft.^3 s^{-1}$) occurred in June 1972 during Hurricane Agnes, and the lowest (0.01 $m^3 s^{-1}$ or 0.38 $ft^3 s^{-1}$) in August 2002. For OPC the highest daily mean discharge occurred in June 2006 (102 $m^3 s^{-1}$ or 3590 $ft.^3 s^{-1}$) and the lowest in September 2007 (0.2 $m^3 s^{-1}$ or 7.3 $ft.^3 s^{-1}$). Mean daily discharge values corresponded to 1.6 $m^3 s^{-1}$ (56.5 $ft.^3 s^{-1}$) and 2.4 $m^3 s^{-1}$ (84.8 $ft.^3 s^{-1}$) for Winters Run and OPC, respectively.

Discharge records available for OPC and Winters Run show significant intra and inter-annual variability (Figures 2.3.9 and 2.3.10). This variation is often tied to precipitation patterns within the area, including episodic climatic events such as storms, hurricanes, and droughts. The annual discharge cycle shows, overall, a characteristic high flow in spring associated with snowmelt followed by low flow in late summer and increase flow again in the fall and winter. Although only four years of discharge data are available for OPC, the larger size of this watershed seems to correspond to a larger water discharge.

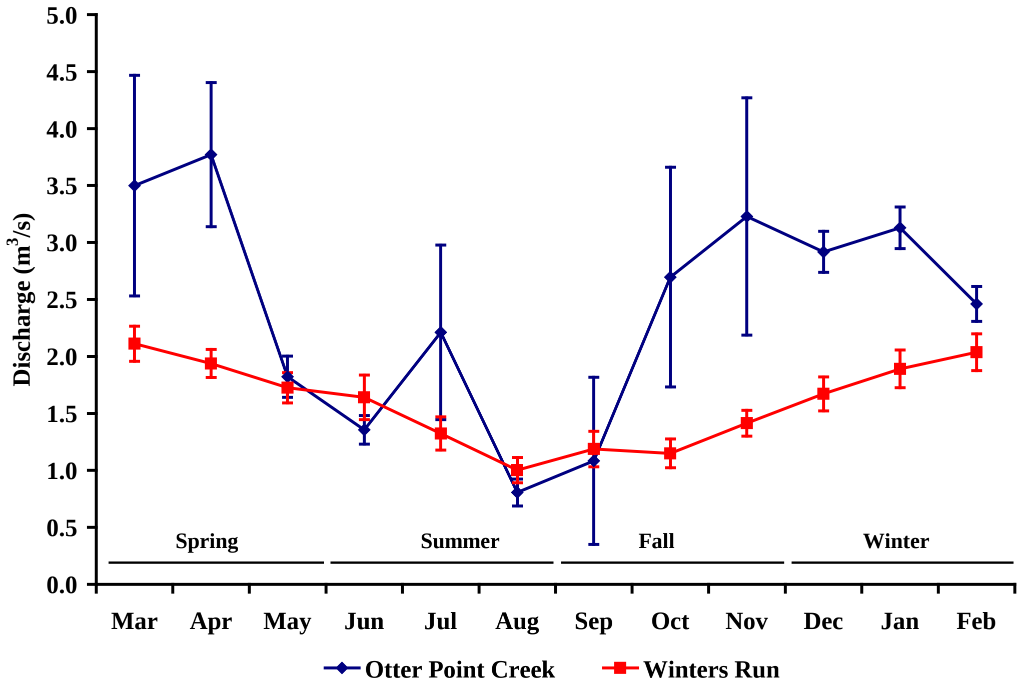


Figure 2.3.9 Mean monthly discharge of OPC (2004-2007) and Winters Run (1967-2007). Data source: USGS Water Resources (http://water.usgs.gov/).

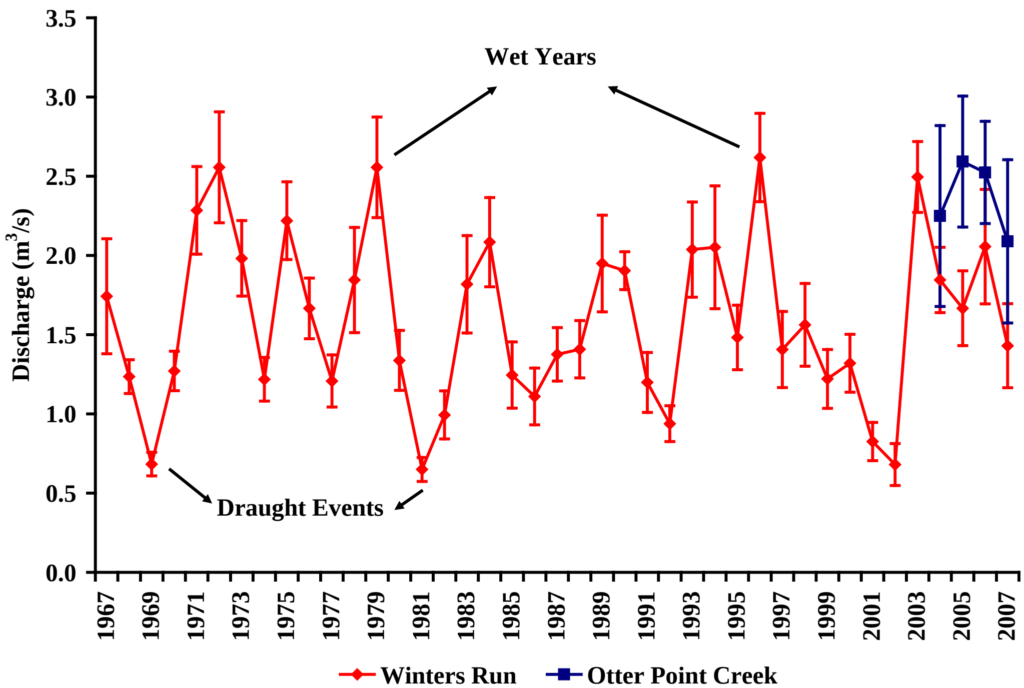


Figure 2.3.10 Mean annual discharge of OPC (2004-2007) and Winters Run (1967-2007). Unusual wet years and draught events are highlighted in the graph. Data source: USGS Water Resources (http://water.usgs.gov/).

Since their construction, the two dams found along Winters Run (Van Bibber Dam and Atkisson Dam both constructed in the 1940's) have restricted flow and have attenuated storm runoff (Figure 2.3.11). Today, however, their capacities have been reduced by almost 100% due to reservoir sedimentation (Tietze 1993, Christine Buckley, personal communication).

Figure 2.3.11 Location of the Atkisson Dam (red symbol), Winters Run, Harford County, Maryland.

The formation of natural logjams has also been found to significantly influence the hydrology and geomorphology of the downstream area of a creek or river. In particular, logjams dissipate hydraulic energy, store water and sediment, encourage bank erosion, redirect flows to different distributaries, and increase habitat diversity. This was the case of two natural logjams that formed upstream of the OPC marsh during Hurricane Agnes in 1972 (Tietze 1993).

Extensive urbanization of the area surrounding OPC has also influenced the wetland hydrology via channelization, sedimentation, storm water diversions, etc. (Tietze 1993). Direct storm water drainage from the adjacent housing developments and trailer park into the OPC marsh also occurs. The Bush River has a slow flushing rate averaging 48 days for complete turnover. This slow flushing rate exacerbates eutrophication, leading to nuisance algae blooms and episodic periods of low dissolved oxygen levels.

2.3.4.2 Tides

Semidiurnal tides characterize the tidal freshwater environment at OPC. Otter Point Creek also lacks a strong 'spring' or 'neap' cycle that is common in many other areas, which may be a result of the shape of the Bush River basin. But overall, water levels at OPC reflect well defined tidal cycles (Pasternack et al. 1994, Pasternack and Hinnov 2003). When the tide rises there is a net input of water and other materials into the system, when the tide falls, there is a net export out of the system; and the flushing rate often responds to river discharge, particularly during the spring season. Depending on the elevation and the position with respect to the river channels, the wetlands at OPC experience regular or seasonal flooding by the tides.

Because flooding is relative to the marsh elevation, a difference on frequency and duration of flooding could be observed between low and high marsh zones. A hydrological study conducted by Pasternack et al. (1994) at OPC showed that the mean high tide in a low marsh area was 1.75 times higher than a high marsh and the tidal range in the low marsh was 1.5 times greater than the high marsh; giving a relative measure of elevation difference between zones. These differences are often translated in different flooding durations, although in OPC, a significant reworking of sediments (leading to sediment deposition) seems to also influence the local hydrological patterns between the low and high marsh.

2.3.4.3 Winds, storms, and hurricanes

In addition to tides, winds have an important effect in OPC hydrology, particularly water levels. As part of a two-year analysis (1995-1996) of wind data, watershed discharge, and water levels, Pasternack and Hinnov (2003) demonstrated a strong coupling between wind and water level changes within the OPC system. They identified two main wind components influencing the OPC marsh, a S-N wind component which follows the alignment of the Bush River (which blows water into OPC) and a W-E component which blows water out of OPC (Figure 2.3.12). The S-N wind component, however, seems to have the greatest effect on OPC water levels. As wind blows harder to the north, water in the Chesapeake Bay is pushed into the Bush River and up into the OPC system increasing water levels there. In contrast to this phenomenon, field accounts have occasionally showed that strong and prolonged W-E winds associated with major storms have caused a significant decrease in the water level at OPC by pushing the water out of the channels and main embayment leaving the subtidal zone exposed for prolonged periods of time. Overall, mean wind speed recorded during 1995-1996 was 2.12 m s^{-1} (4.7 mph), and less than 5.15 m s^{-1} (11.5 mph) during 90% of the time.

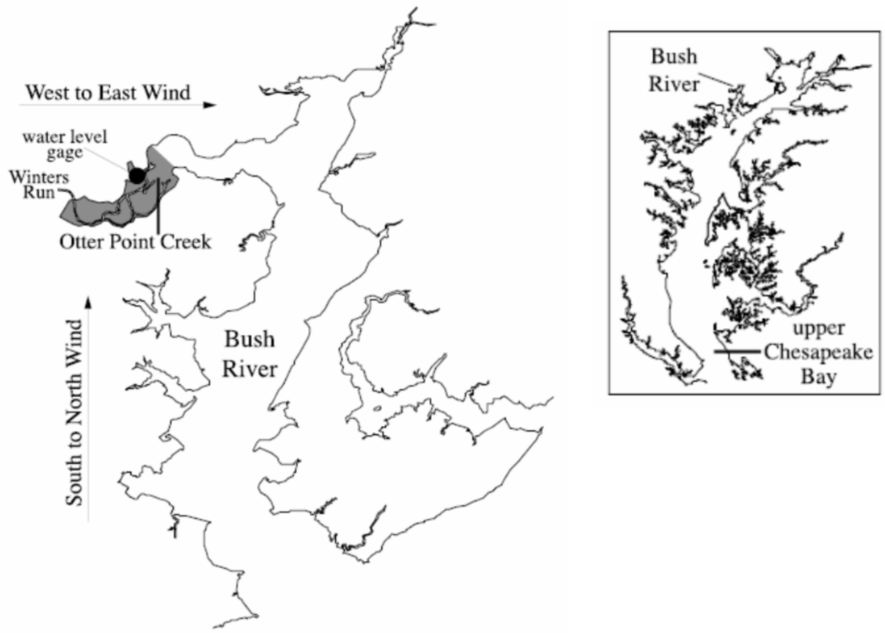


Figure 2.3.12 Main wind components affecting water levels in and around the OPC tidal freshwater marsh. Source: Pasternack and Hinnov (2003).

As part of the same study, Pasternack and Hinnov (2003) also showed that variations on local and remote watershed discharge (Winters Run and Susquehanna River) did not have a measurable impact on OPC water levels. Even during hurricanes, the riverine signal was swamped out by the high water level fluctuations driven by winds and storm surge (Pasternack and Hinnov 2003). For example, Hurricane Felix, which occurred on August 1995, caused a water level increase in OPC that lasted for about four days, which was the result of the hurricane's storm surge as it propagated up the Chesapeake Bay. It is important to note that while estuarine processes control the hydrodynamics of the OPC tidal freshwater system (Pasternack and Hinnov 2003), watershed processes control sediment delivery (Pasternack et al. 2001).

2.3.4.4 Groundwater

The main drinking water supplies in Harford County come from both surface water withdrawals and groundwater. Many of the residents within the Bush River basin, including the town of Bel Air, use water withdrawn from Winters Run and wells, some located in the Church Creek and Deep Spring Branch sub-basins.

Considering the great importance of groundwater as a source of drinking water to the county, there is a common interest to maintain the integrity of this valuable resource. Some sources of potential groundwater contamination have been identified, including the leaking of septic systems, infiltration of agricultural runoff, and leaking of contaminants from waste disposal sites, particularly those associated with the Aberdeen Proving Ground.

As far back as 1965, leaking septic systems along the shoreline were identified as major contributors to the high bacterial loadings in OPC and the Bush River. A study conducted by CH2M-Hill (1983) for Harford County determined that bacterial levels in OPC were usually within state water quality standards, but these levels increased rapidly and dramatically under wet weather conditions.

In an effort to better understand the potential sources of water contamination through the leakage of septic systems within the Bush River watershed, Harford County performed a desktop assessment of illicit discharge potential- IDP (Harford County 2006). One of the factors evaluated during this assessment included the density of aging septic systems. Improved parcels with structures built before 1970 were selected from the cadastral layer. The parcels were then coded by subwatershed; densities were calculated and assigned to one of the following categories: Low IDP Risk: 0-49 sites per square mile; Medium IDP Risk: 50-99 sites per square mile; and High IDP Risk: 100+ sites per square mile (Figure 2.3.13).

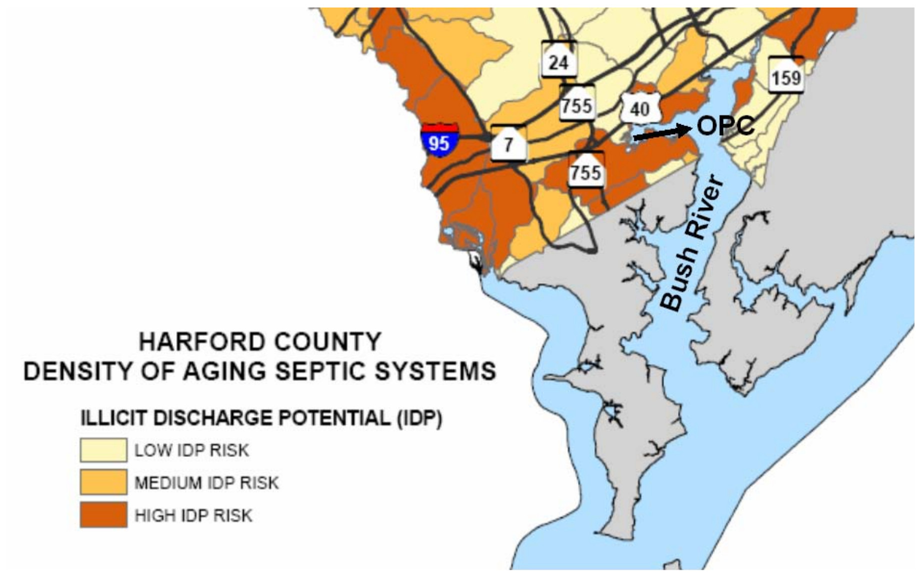


Figure 2.3.13 Illicit discharge potential (IDP) within the Bush River watershed, expressed as the density of aging septic systems. Source: Harford County, Maryland (2006).

The IDP risk, defined by the density of aging septic systems, could be characterized as mostly high around OPC, with the exception of a section towards the north-west side (Figure 2.3.13). However, most of the area in the immediate vicinity of the Reserve component is served by public sewer which would not contribute to nutrient enrichment of ground water as long as the system integrity is preserved.

Another potential source of groundwater contamination could be linked to the Aberdeen Proving Ground (APG), located 15 miles northeast of Baltimore. APG is divided into two main areas separated by the Bush River. The area north of the Bush River is referred to as the Aberdeen Area, and the area south of the Bush River is referred to as the Edgewood Area-Aberdeen Proving Ground (APG-EA; Figure 2.3.14). The Edgewood Area was established in 1917 as the primary chemical warfare research and development center for the Army and it has also been the location of production-scale chemical agent manufacturing. Until the early 1970s, the primary methods of waste disposal at APG-EA were through burial, open detonation, open-air burning, or by discharging untreated liquid wastes through sewer lines to surface water. Over the years, these operations resulted in contamination of the environment with hazardous materials, including groundwater contamination (EPA Article, September 2005).

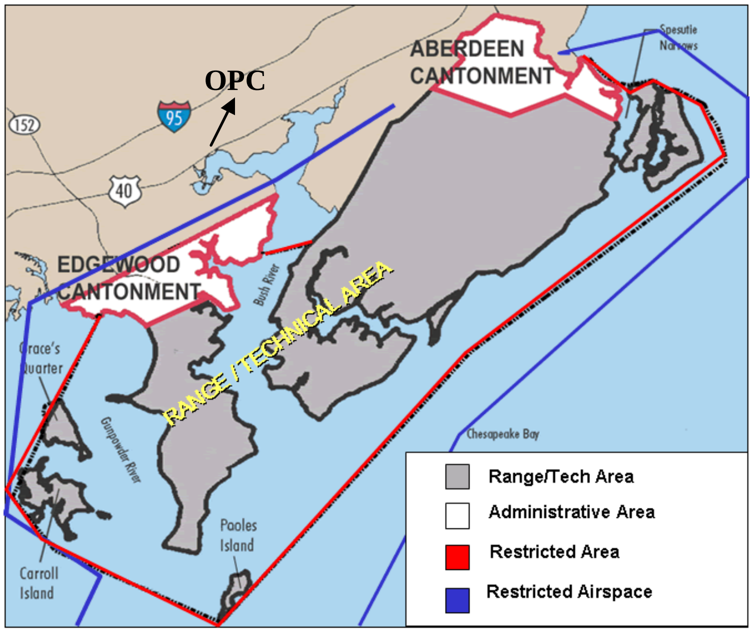


Figure 2.3.14 Property boundaries of Aberdeen Proving Ground including the Aberdeen and Edgewood areas. The total area covers more than 29,340 hectares (72,500 acres).

Because of its history, all the land areas of this site are contaminated or potentially contaminated. Substances that have been disposed include napalm, white phosphorus, and chemical agents. In addition to land areas, on-site surface waters that have also potentially been contaminated include rivers, streams, and wetlands (EPA Article, September 2005).

Contamination of land and water around the Edgewood-area is of concern because approximately 38,600 people live within three miles of the site, in addition to on-site residents. Four Edgewood-area standby water supply wells served approximately 3,000 people, but these have been abandoned. The Long Bar Harbor well field of the County Department of Public Works and the well field used by the Joppatowne Sanitary Subdistrict serve 35,000 people within three miles of the site. On-site groundwater sampling has identified various metals, volatile organic compounds (VOCs) and chemical warfare agent degradation products. On-site soil contamination sampling has identified various VOCs, metals, and unexploded ordnance in surface and subsurface soil. On-site surface water sampling has identified various metals, pesticides, phosphorus, and VOCs. People who accidentally ingest or come in direct contact with contaminated groundwater, surface water, soil, or sediments may be at risk. This contamination may also impact wildlife; this area is considered important habitat for bald eagles. Since the early 90's, actions have been taken to remediate some of the problems and efforts have continued through the years (EPA Article, September 2005).

The Michaelsville Landfill is located within the Aberdeen Area and is a 20-acre landfill operated as a sanitary landfill from the 1970s until 1980. Also in this area are the Phillips Field Disposal Area, the White Phosphorous Munition Burial Site, and numerous known or suspected solid waste management units that may be sources of contamination. Groundwater and surface water sampling identified various heavy metals, phosphorous, and VOCs and explosives. There is also soil contamination with pesticides and PCBs, VOCs and petroleum hydrocarbons. In 2003 the construction of a groundwater treatment plant was completed to protect the Perryman Well field which is the source of drinking water for most of Harford County.

Both the Harford County and City of Aberdeen Production (CAP) wells are located in the northern Aberdeen Area. Historical range activities at this site have contaminated Perryman and CAP wells, which provide drinking water to Harford County residents. In addition, there are two on-post groundwater supply wells located in the Edgewood Area (H-Field test range and Westwood) that are used to produce water for vehicle washing, well drilling, and equipment decontamination. There are also private wells adjacent to the installation boundary. The wells must be protected from further contamination.

Finally, ground water from agricultural activities in some portions of the Chesapeake Bay has been found to contribute high nutrient loadings, particularly nitrates to the receiving waters. Within OPC, no specific studies of ground water nutrient concentrations have been conducted; therefore the overall level of groundwater contamination (from different sources) is not known. This is an important information gap that needs to be addressed.

2.3.5 Land and Water Use History

2.3.5.1 Historical changes

Subsistence agriculture of corn as well as hunting and gathering practices occurred from about 500 BC to the time of European colonization, which began around 1658 AD. Tobacco agriculture dominated early European commerce until the early 1800's when agriculture shifted to corn and other vegetables. Land use continued to be agricultural until around 1930 when many farms were abandoned. Residential and suburban development greatly expanded from 1930 to the present time, with the rate of growth accelerating after 1960. At present, OPC is surrounded by the developments of Edgewood Heights, Edgewood Meadows, Harbor Oaks, and Westshore. A golf course and the Anita C. Leight Estuary Center are also situated in the watershed along with single family residential and high density town house developments close to the water.

Historical changes have been recorded through old maps and aerial photographs. OPC and the land surrounding have gone through shifts from open water to forested wetland. Much of the current marshlands that are located at the upper end of OPC near the present U.S. Route 40 were deforested in the early 1900's. Present day Snake Island was a hummock only 35 meters (115 feet) wide, surrounded by freshwater tidal marsh. Existing islands in the early 1900's have since then become submerged due to marsh advancement. The islands have also been succumbing to erosion and rising sea level for thousands of years, but the marsh appears to have developed only recently, during the late 1950's and early 1960's. Aerial photographs taken prior to 1972 show that the forest-land had re-established on both sides of Winters Run and OPC.

In 1917 the Aberdeen Proving Ground was established on 31,970 hectares (79,000 acres) of land just south of the OPC component. In 1918 the Edgewood Arsenal took over 3237 hectares (8,000 acres) of farmland which had been the property of General Cadwalander who farmed it from 1846 to 1918. The military properties apparently did not engage in extensive clearing of forests during this time. Although the Military Proving Grounds at Aberdeen and the Army Arsenal were active from the Civil War onward, the major increase in employment at these two adjacent military facilities occurred during World War II. Road and housing construction, and commercial development all accelerated with the increase in employment opportunities. U.S. Route 40 was completed around 1938 forming a road embankment 3.7 to 4.6 meters (12 to 15 feet) high across Winters Run.

During the early 1940's a wastewater treatment plant was constructed on the lower Winters Run in response to obvious water quality problems. Much of the construction activity was an attempt to catch up with the effects of rapid population growth, porous soils, and a high water table. During the 1960's two sewage oxidation ponds were constructed in the marsh and were in use as a temporary treatment facility pending the completion of interceptor lines, pumping stations and a larger treatment facility outside the watershed. This era marks a major change in the area now included in the Reserve.

With the construction boom, areas of open water transitioned into forested wetlands as sediment accumulation at the mouth of Winters Run accelerated. The original marsh peat may have been buried under layers of upland derived soils. OPC adjacent to the current Anita C. Leight Estuary Center property was at least 3.5 meters (11.5 feet) deep prior to the 1940's. A thriving commercial fishery existed at the site. As the creek accumulated sediment the marsh was able to expand seaward and increase its aerial extent.

Earth moving equipment altered the land surface in the marsh (even as it was forming) as sewer lines were constructed across the wetland and a pumping facility was built. The first and second sewage oxidation ponds were built in the marsh to be a temporary response to real estate development in the area. They provided increased sewage treatment capacity for a decade while interceptor lines and pumping stations were constructed to remove the sewage to the Aberdeen plant for treatment, and their construction added fill to the marsh.

As mentioned in a previous section (2.3.4.1 River discharge), Winters Run has two water supply dams already in existence and several more water supply dams proposed. The largest existing reservoir, Atkisson Reservoir, is so filled with silt that it no longer functions as a water supply. The former lake is over two-thirds emergent vegetation. The second water supply impoundment at Van Bibber is also rapidly filling with sediment and has several patches of emergent vegetation behind the dam. The high erodibility of the soil in the watershed is both a historic and a current problem.

2.3.5.2 Recent land use change and trends

Because OPC is dominated by the flow of Winters Run and to a lesser extent HaHa Branch, any activity in these watersheds influences what happens in the estuary. Land use changes in the watershed can have a significant cumulative impact on the estuary (Copeland et al. 1983). Agricultural activities which expose soil are obvious contributors to increased soil erosion and down stream deposition. However, studies by the University of Maryland (ICPRB 1991) have documented a six fold increase in sediment loading in coastal plain streams as the predominant land use shifted from agricultural to residential. Considering that OPC is located downstream of a rapidly urbanizing watershed, the sediment as well as nutrient contribution via runoff are significant. The OPC marsh would probably have expanded even more than it has, had not a substantial portion of the sediment load in Winter Run deposited behind existing upstream dams.

By 2006, 62% of the OPC subwatershed has been developed or is used for agriculture, while 38% still remains as forested land (Figure 2.3.15).

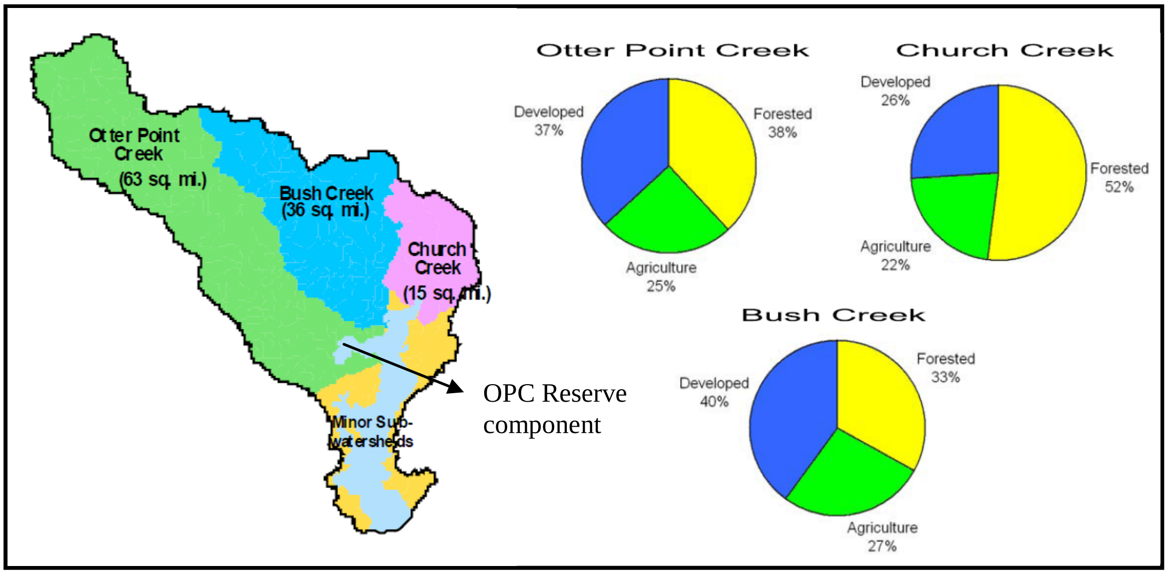


Figure 2.3.15 Land use cover for the OPC subwatershed, Bush River. Graph developed in 2006 by Harford County Water Resources.

A closer look of land use within the surrounding areas of OPC is shown in Figures 2.3.16 and 2.3.17. Although the OPC component itself is mostly constituted by deciduous forest, wetlands, and water (Figure 2.3.17), most of the Reserve is surrounded by developed areas and some agricultural lands, with few sections bordered by forest (2.3.16).

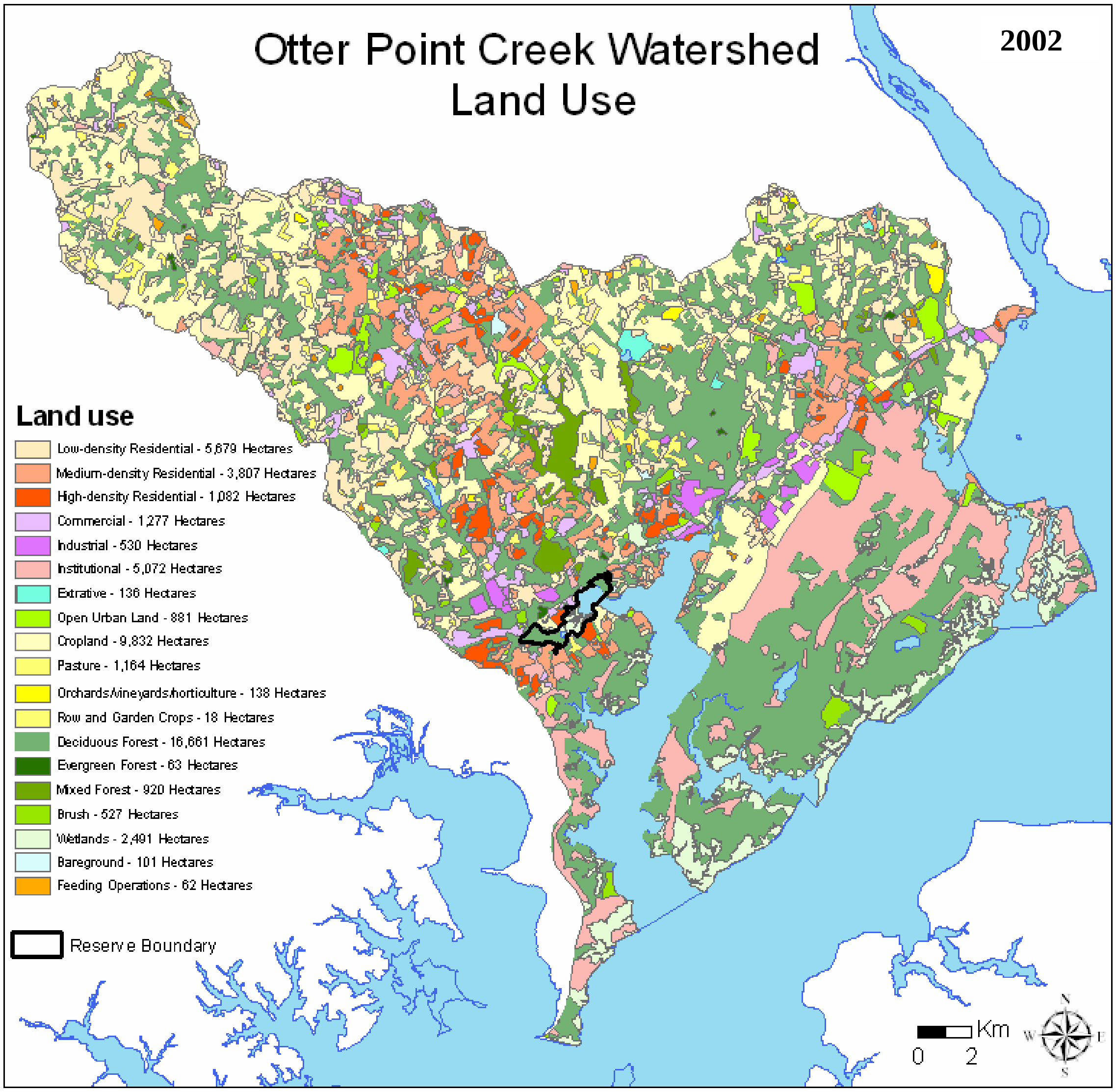


Figure 2.3.16 Land use and land cover (hectares) map for OPC and surrounding subwatersheds for 2002.

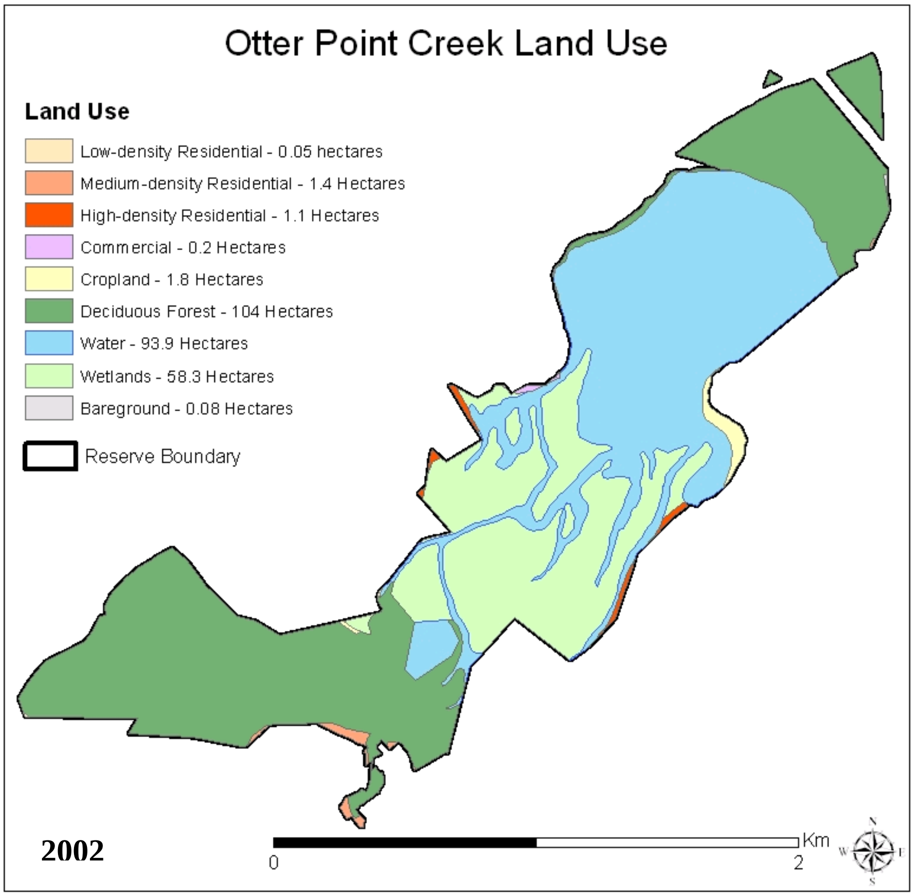


Figure 2.3.17 Land use and land cover (hectares) of the OPC component property for 2002.

2.3.6 Water Quality

The 1998 Maryland Clean Water Action Plan established priorities for watersheds in "need of restoration". In the Plan, a watershed is considered a Category one priority watershed (highest state priority for restoration) if it shows violation of water quality standards and poor values for other natural resource indicators, including submerged aquatic vegetation, fish, and benthic communities. The Bush River basin was included as a Category one priority watershed (Clean Water Action Plan Technical Workgroup 1998).

Although the OPC component is located within the Bush River Basin; local water quality conditions may vary due to variability associated to local driving factors such as river discharge, weather conditions, and land use activities. Therefore, in an effort to better characterize the water quality within the Reserve boundaries, data that has been collected in OPC and the Bush River through Maryland DNR and the Reserve's System Wide Monitoring Program (SWMP) was analyzed and results are presented in this section.

Two long-term continuous monitoring stations (CONMON) or automated dataloggers were established within the Bush River (CONMON stations are part of the NERRS system wide monitoring program - SWMP). One of the stations, located in Lauderick Creek (39.4039 N, -76.2728 W), was installed by Maryland DNR and remained active from 1984 - 2007. In 2008, this station was moved to a new location in Church Point (39.4582 N, -76.2323 W); a second station located in OPC (39.4508 N, -76.2746 W) was established in 2003 as part of the Reserve's water quality monitoring program and it is still active (Figure 2.3.18). These stations monitor various water quality parameters including water temperature, specific conductivity, salinity, percent saturation, dissolved oxygen, depth, pH, and turbidity; information is recorded every 15 minutes. All available data that has been collected through both stations could be viewed and downloaded from the Maryland Department of Natural resources eyesonthebay website: http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm and/or the Centralized Data Management Office website: (http://cdmo.baruch.sc.edu/).

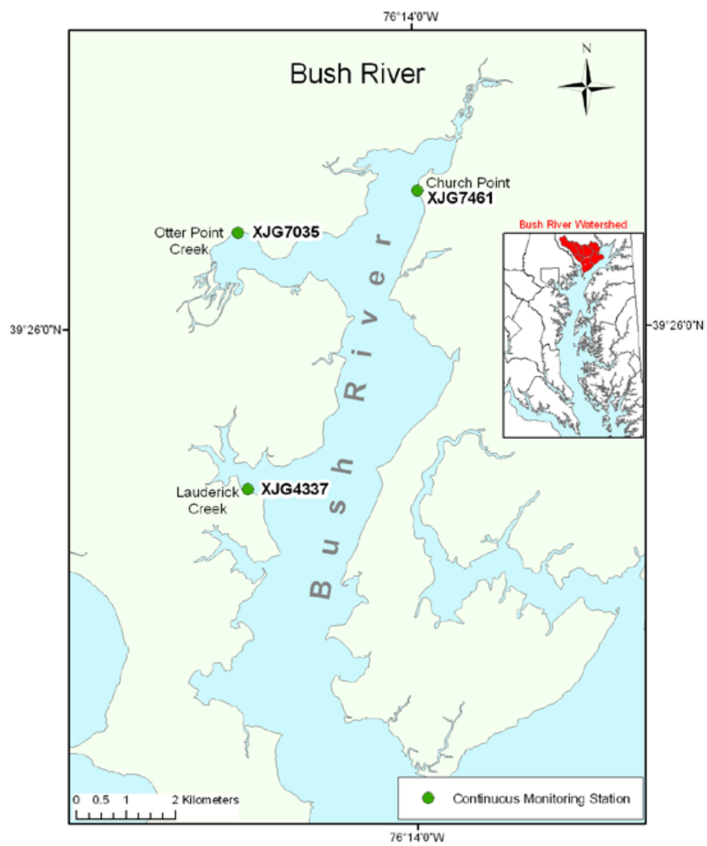


Figure 2.3.18 Continuous water quality monitoring stations (CONMON) at OPC, Bush River. CONMON stations are part of the NERRS system wide monitoring program (SWMP). Source: Smith et al. (2009).

In addition of measuring the water quality parameters described above, water samples are collected at each of these stations: twice a month at the OPC CONMON station and once a month at Lauderick Creek, Church Point, and six additional stations within OPC (Figure 2.3.19). These samples are sent to the Chesapeake Biological Laboratory, University of Maryland Center for Environmental Studies to be analyzed for nutrients including: ammonium, nitrite, nitrate/nitrate, and phosphate, total nitrogen and total phosphorus. Additional analyses per sample include chlorophyll *a*, total suspended solids, and total volatile solids.

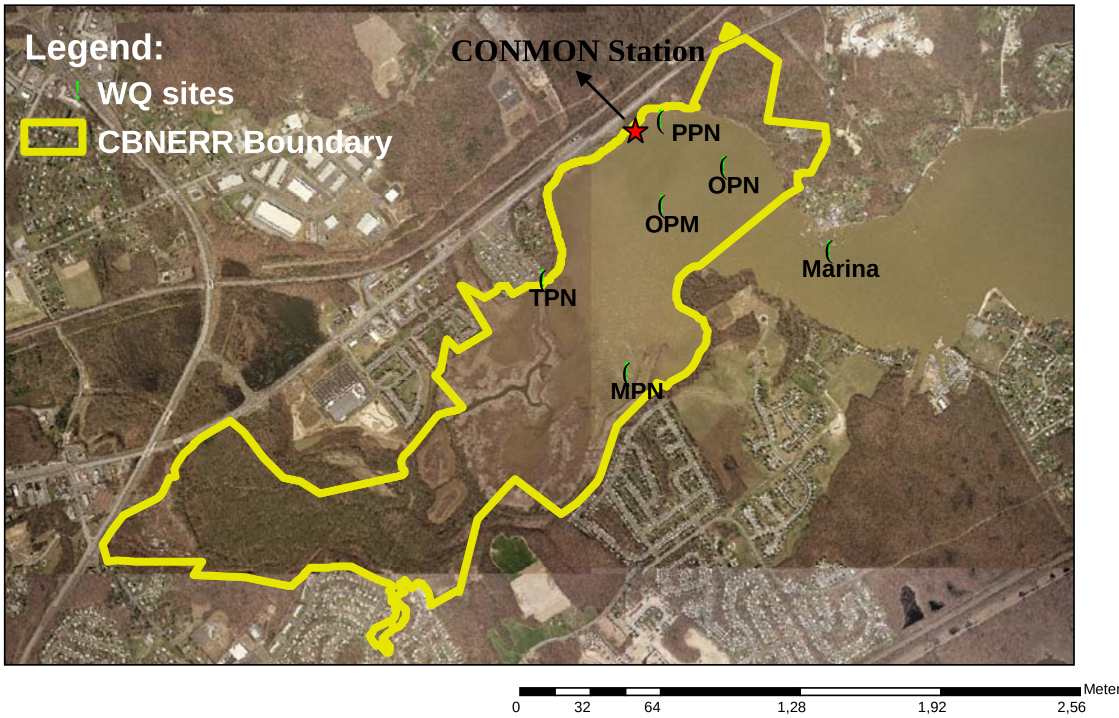


Figure 2.3.19 Location of a continuous water quality monitoring station (CONMON) and six additional discrete water quality stations at Otter Point Creek. Beginning in 2011, the six discrete water quality stations were cut to three stations: MPN, TPN, and Marina.

In an effort to achieve and maintain the water quality conditions needed to protect the aquatic living resources of the Chesapeake Bay, the U.S. Environmental Protection Agency (USEPA) Region III developed guidance and water quality criteria that could be used by the local and state government to address nutrient and sediment-based pollution in the Chesapeake Bay and its tidal tributaries. These water quality criteria are based on dissolved oxygen, water clarity, and chlorophyll *a* and were developed for five essential aquatic habitats or use zones: migratory fish, shallow water, open water, deep water, and deep channel (USEPA 2003; Figure 2.3.20). An analysis of each of these criteria was conducted using data collected through the Reserve's water quality monitoring program and will be discussed in the following sections.

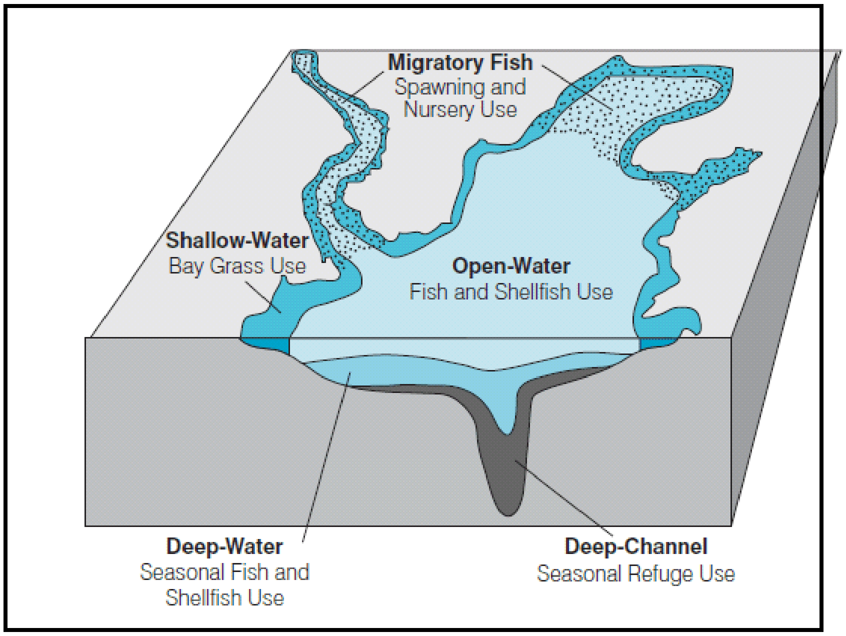


Figure 2.3.20 Conceptual illustration of the five Chesapeake Bay essential aquatic habitats and their designated use. Shallow water corresponds to the habitat found within the OPC component. Source: USEPA (2003).

2.3.6.1 Dissolved oxygen (DO)

Providing a characterization of dissolved oxygen for the Chesapeake Bay can easily become a very difficult task as many different biological, physical, chemical, human, and environmental factors and processes need to be considered. In addition, spatial and temporal variability also plays an important role in defining specific conditions in a particular region (USEPA 2003). Overall, dissolved oxygen in the Chesapeake Bay is characterized as naturally low, especially in deeper waters, as a result of the Bay's physical morphology and estuarine circulation. Characteristics such as prolonged stratification, long residence times, low tidal energy, and high productivity contribute to these low oxygen conditions and are comparable to similar estuarine systems (Boynton et al. 1982, Nixon 1988, Caddy 1993, Cloern 2001).

A dissolved oxygen criteria developed by USEPA for the Chesapeake Bay is presented in Table 2.3.1. These criteria were developed considering the DO needs required for the survival, growth, and reproduction of natural resources using and living in each of five essential aquatic habitats and for the protection of their designated uses (USEPA 2003).

Table 2.3.1 Chesapeake Bay dissolved oxygen criteria developed by each of five essential aquatic habitats and their designated use. Shallow water corresponds to the habitat found at OPC. Source: USEPA (2007).

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	7-day mean > 6 mg liter-1 (tidal habitats with 0-0.5 ppt salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species.	February 1 - May 31
	Instantaneous minimum > 5 mg liter^{-1}	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species.	
	Open-water fish and shellfish designated use criteria apply		June 1 - January 31
Shallow-water bay grass use	Open-water fish and shellfish designated use criteria apply		Year-round
Open-water fish and shellfish use	30-day mean > 5.5 mg liter^{-1} (tidal habitats with 0-0.5 ppt salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species.	Year-round
	30-day mean > 5 mg liter^{-1} (tidal habitats with >0.5 ppt salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species.	
	7-day mean > 4 mg liter^{-1}	Survival of open-water fish larvae.	
	Instantaneous minimum > 3.2 mg liter^{-1}	Survival of threatened/endangered sturgeon species.[1]	
Deep-water seasonal fish and shellfish use	30-day mean > 3 mg liter^{-1}	Survival and recruitment of bay anchovy eggs and larvae.	June 1 - September 30
	1-day mean > 2.3 mg liter^{-1}	Survival of open-water juvenile and adult fish.	
	Instantaneous minimum > 1.7 mg liter^{-1}	Survival of bay anchovy eggs and larvae.	
	Open-water fish and shellfish designated-use criteria apply		October 1 - May 31
Deep-channel seasonal refuge use	Instantaneous minimum > 1 mg liter^{-1}	Survival of bottom-dwelling worms and clams.	June 1 - September 30
	Open-water fish and shellfish designated use criteria apply		October 1 - May 31

[1] At temperatures considered stressful to shortnose sturgeon (>29 °C or 84.2 °F), dissolved oxygen concentrations above an instantaneous minimum of 4.3 mg liter^{-1} will protect survival of this listed sturgeon species.

Dissolved oxygen levels at OPC for the top and bottom water layers are often above 5.0 mg l^{-1}, which falls within the EPA criteria indicated in Table 2.3.1. The analysis of water quality data collected from six OPC discrete water quality stations (Table 2.3.2) during the period between June 2002 and September 2008 shows a surface DO average value for the entire area of 8.07 mg l^{-1} and a DO value of 7.53 mg l^{-1} for the bottom layer. Dissolved oxygen values at the different stations ranged between 7.54 and 8.39 mg l^{-1} for the top water layer and between 7.15 and 7.90 mg l^{-1} for the bottom layer (Table 2.3.2). Overall DO values are slightly lower in the bottom layer, but still above the standard value of 5.0 mg l^{-1}.

Table 2.3.2 Average values of water physical/chemical parameters monitored at OPC. MPN, TPN, OPM, PPN, OPN, and Marina correspond to the six stations being monitored at this Reserve component (Figure 2.3.19).

Station	**Secchi Depth (m)**	**Total Depth (m)**	**pH**	**Salinity (ppt)**		**DO (%)**		**DO (mg/l)**		**Temperature (C°)**	
				Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
MPN	0.42	0.66	7.90	0.20	0.20	88.21	83.89	7.54	7.15	23.50	22.90
se	0.02	0.04	0.10	0.04	0.05	3.44	3.50	0.27	0.28	0.60	0.60
TPN	0.53	1.41	7.70	0.20	0.20	90.16	84.37	7.81	7.36	23.20	22.30
se	0.03	0.04	0.10	0.03	0.04	2.90	2.80	0.26	0.26	0.60	0.60
OPM	0.48	1.01	8.00	0.30	0.40	96.52	90.52	8.29	7.83	23.90	23.50
se	0.02	0.03	0.10	0.07	0.07	2.78	2.74	0.26	0.25	0.70	0.60
PPN	0.40	0.73	8.40	0.40	0.30	98.62	92.78	8.39	7.76	24.50	24.00
se	0.02	0.03	0.10	0.07	0.07	3.42	3.48	0.25	0.30	0.70	0.70
OPN	0.44	0.97	8.20	0.40	0.40	100.29	92.21	8.34	7.90	24.70	23.90
se	0.02	0.05	0.10	0.08	0.08	2.94	3.32	0.24	0.27	0.60	0.60
Marina	0.44	2.68	8.10	0.40	0.40	94.93	83.48	8.02	7.16	23.70	23.10
se	0.03	0.17	0.10	0.08	0.09	3.12	2.92	0.27	0.28	0.70	0.60
Average	0.45	1.24	8.05	0.32	0.33	94.79	87.88	8.07	7.53	23.91	23.29
se	0.00	0.02	0.00	0.01	0.01	0.11	0.14	0.00	0.01	0.02	0.00

se = standard error
Average values were calculated based on data collected during 2002-2008.

Even though DO levels during most of the year fall within high values, during warmer periods and episodic algae blooms the DO levels may drop below 5.0 mg l^{-1} or even 3.0 mg l^{-1}. These occurrences may impact the aquatic life, particularly benthic invertebrates in the open water areas.

Within OPC, a shallow-water tidal environment with an average depth of 1.24 m (4.1 ft.), diel cycles of low DO conditions are often the result of local production and respiration. At night, for example, water-column respiration temporarily reduces DO levels (D'Avanzo and Kremer 1994). Climatic conditions such as calm winds and several continuous cloudy days can also contribute to oxygen depletion. Shallow-water habitat, such as the one in OPC, can be exposed to episodes of extreme and rapid DO fluctuations (Sanford et al. 1990).

Overall, the timing, extent, and frequency of reduced DO conditions in OPC and similar environments can vary from year to year, driven in great part by local weather patterns, the timing and magnitude of freshwater river flows, the concurrent delivery of nutrients and sediments into tidal waters and the corresponding springtime phytoplankton bloom (Officer et al. 1984, Seliger et al. 1985, Boynton and Kemp 2000, Hagy 2002 cited by USEPA 2003).

Other parameters measured as part of water quality monitoring at OPC include salinity, temperature, and pH. The low average salinity of 0.32 parts per thousand (ppt) is characteristic of this tidal freshwater environment; however, salinities of 3-5 ppt could be measured during episodic drought conditions. The average value for water acidity (pH) and temperature at OPC is 8.05 and 24 °C (75.2 °F), respectively; both meet state standards for healthy aquatic life. Occasionally, a temporarily increase of pH in low salinity environments such as OPC is an indication that a blue-green algal bloom (e.g. *Microcystis* blooms) may be occurring.

2.3.6.2 Water clarity

Lack of water clarity or turbidity within OPC follows an annual pattern that is linked to a certain extent to the presence of underwater grasses, also referred to as submerged aquatic vegetation or SAV. Turbidity starts to decrease during the beginning of the SAV growing season with the lowest values often observed during the peak of SAV biomass; turbidity then starts to increase by the end of the growing season (October) initiating a new cycle (Figure 2.3.21). Submerged aquatic vegetation helps improve water clarity through the settlement of suspended sediments and the stabilization of bottom sediments preventing resuspension. However, excessive sediments in the water can also cause the smothering and death of SAV by reducing light penetration through the water column limiting/inhibiting their photosynthesis activity and growth.

Changes in water clarity are also associated to precipitation and the occurrence of storms and hurricanes; heavy rains often carry sediments to the system through runoff causing turbidity spikes. These events increase the variability of observed turbidity patterns at OPC within and among years. For example the turbidity spike shown in Figure 2.3.21 could be linked to the high precipitation received during the month of July in 2004 (Figure 2.3.22).

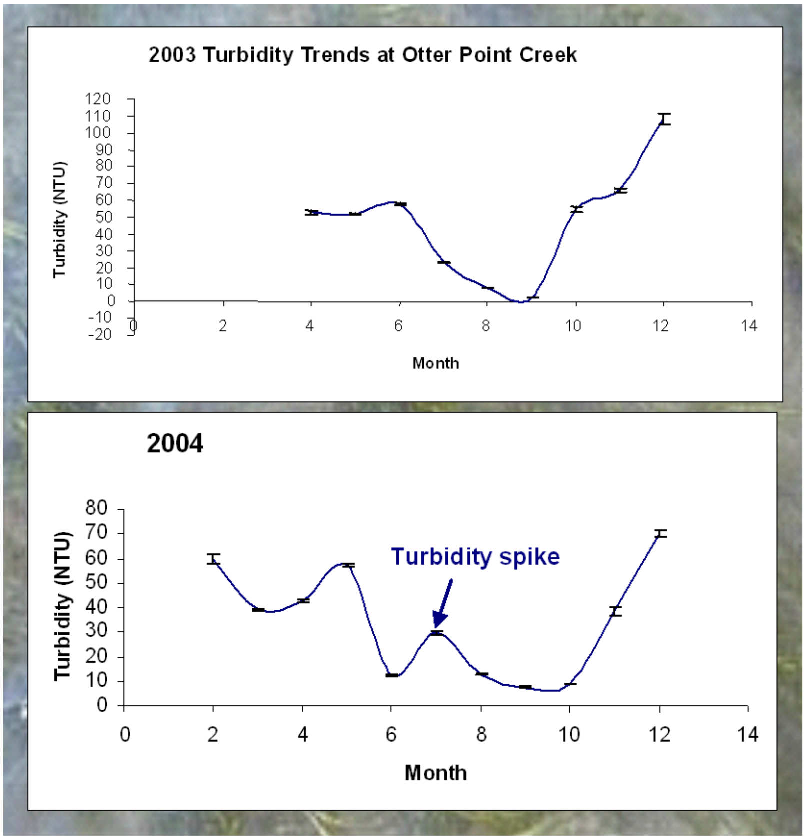


Figure 2.3.21 Turbidity trends observed at OPC during 2003 and 2004.

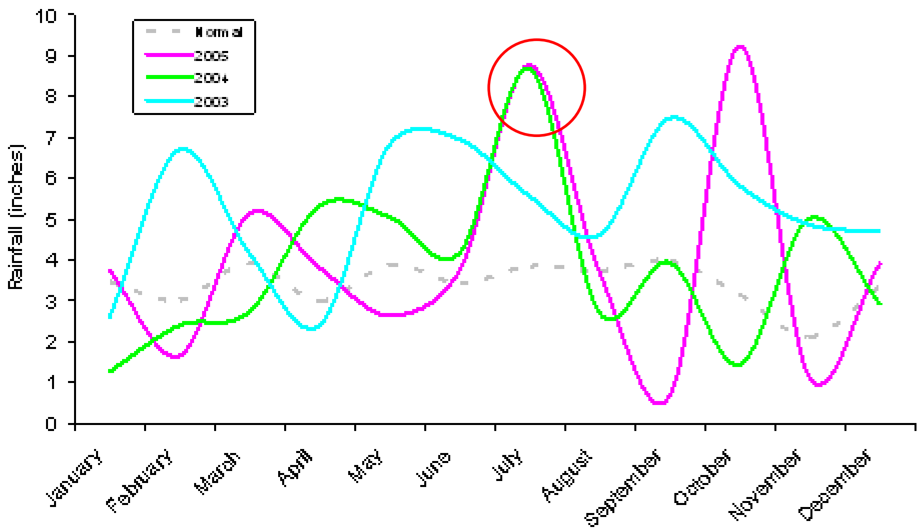


Figure 2.3.22 Monthly average rainfall recorded from the weather station located in the Baltimore Washington International Airport for the period 2003-2005 (Station location: 39°10'N / 76°41'W).

As a result of the relationship between SAV and turbidity, it is expected that significant changes in the SAV population coverage would result in changes of local water clarity conditions. Little or no SAV was found in the Bush River in the 1990's. However, underwater grasses reappeared in the Bush River in 2000 (Trice et al. 2007) and have maintained a constant presence in the river until now contributing to improved water quality in the river. The abrupt decline of SAV in the Bush River before their reappearance in 2000 is believed due primarily to the high turbidities derived from land clearing activities that took place upstream of the marsh. The ability of the marsh to retain and cycle the input of sediments and nutrients from the watershed appears to have been significantly degraded in 1972 following Hurricane Agnes.

Studies conducted by the University of Maryland and reported in the newsletter of the Interstate Commission on the Potomac River Basin (December 1992) indicate that a middle Atlantic coastal plain stream, the Anacostia, has accumulated more than 12.2 vertical meters (40 vertical feet) of sediment in the flood plain over the past 200 years. This is less than the rate of sedimentation for streams in geologically active regions. Some west coast rivers have accreted 24.4 vertical meters (80 vertical feet) of sediment in as little as 100 years.

Similarly to the DO criteria developed by USEPA for the Chesapeake Bay, water clarity criteria were also developed. These criteria were developed to establish the minimum level of light penetration required to support the survival, growth, and continued propagation of underwater bay grasses (Table 2.3.3). These criteria is given as percent ambient light at the water surface extending through the water column and the equivalent secchi depth by application depth and because it pertains directly to SAV it is only applied during the underwater grasses growing season (USEPA 2003).

Table 2.3.3 Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats. Source: USEPA (2003).

Salinity Regime	Water Clarity Criteria as Percent Light-through-Water	Water Clarity Criteria as Secchi Depth								Temporal Application
		Water Clarity Criteria Application Depths								
		0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	
		Secchi Depth (meters) for above Criteria Application Depth								
Tidal fresh	13 %	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 – Oct 31
Oligohaline	13 %	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 – Oct 31
Mesohaline	22 %	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	April 1 – Oct 31
Polyhaline	22 %	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	Mar 1 – May 31 Sep 1 – Nov 30

Within the OPC embayment, the average total depth and secchi depth (calculated from a 7-year data record: 2002-2008 and excluding the Marina station) is of approximately 0.95 m ± 0.004 m (3.1 ft. ± 0.01 ft.) and 0.45 m ± 0.002 m (1.48 ft. ± 0.007 ft.), respectively. Although the secchi depth (0.7 m) at OPC is somewhat lower than the value that corresponds to the 1.0 m (3.28 ft.) water clarity criteria application depth for the tidal fresh habitat (Table 2.3.3), SAV monitoring observations within this area during the last three years has shown the existence of a healthy underwater grass community. It is important to indicate, however, that *Hydrilla verticillata* (an invasive underwater grass species) dominates in abundance; this species' light requirement was not considered for the development of this criteria and it is probably lower than any of the native species.

2.3.6.3 Chlorophyll *a*

Chlorophyll *a*, a common photosynthetic pigment often associated with other pigments in freshwater and coastal marine phytoplankton, has been used for many years as a main indicator of the amount and quality of phytoplankton (Flemer 1970). Considering that high algal biomass (high chlorophyll *a* levels) is associated with low water quality, the USEPA developed a recommended chlorophyll a criteria for the Chesapeake Bay. This criteria does not provide specific concentration values, but instead is based on the narrative written below. This approach provides the opportunity and flexibility for the development of more accurate and applicable site specific numeric criteria.

"Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences (i.e., reduced water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions) or otherwise render tidal waters unsuitable for designated uses" (USEPA 2003).

Information from the scientific literature was summarized to obtain an indication of the trophic status of a system based on the concentration of chlorophyll *a* (USEPA 2003). Based on this information and knowing that the average chlorophyll *a* value for the OPC embayment is 17.01 ug l^{-1} (± 0.22), the OPC system could be considered as eutrophic (Table 2.3.4).

Wetzel, in his Limnology text, defines eutrophic systems as having chlorophyll *a* concentrations greater than 10 µg $liter^{-1}$ and having few dominant phytoplankton species. Subsequently, he defines a system as eutrophic when it has: (1) very high productivity, but mostly occurring in the lower trophic levels (e.g., algae, bacteria); (2) a simplified structure of biological components; and (3) reduced ability to withstand severe stresses and return to pre-stress conditions (Wetzel 2001).

Table 2.3.4 Trophic status of different aquatic systems characterized by mean chlorophyll a concentrations (µg $liter^{-1}$); cited by USEPA (2003).

Aquatic System	Trophic Status	Wetzel (2001)	Ryding and Rast (1989)	Smith et al. (1999)	Molvaer et al. (1997)	Novotny and Olem (1994)
Fresh-water	Eutrophic	>10	6.7-31	9-25	-	>10
	Mesotrophic	2-15	3-7.4	3.5-9	-	4-10
	Oligotrophic	0.3-3	0.8-3.4	<3.5	-	<4
Marine	Eutrophic	-	-	3-5	>7	-
	Mesotrophic	-	-	1-3	2-7	-
	Oligotrophic	-	-	<1	<2	-

Sources: Molvaer et al. 1997, Novotny and Olem 1994, Ryding and Rast 1989, Smith et al 1999, Wetzel 2001.

Once a system becomes eutrophic, high algae production can lead to low dissolved oxygen conditions, reduced water clarity, harmful algal blooms, and other ecological impairments that reflect alterations of the aquatic food web.

Additionally, scientists have developed a diagnostic tool to calculate the relative contributions of chlorophyll *a* versus total suspended solids to low light penetration in the water column (Batiuk et al. 2000; Gallegos 2001 cited by USEPA 2003). Chlorophyll *a* criteria derived from the use of this diagnostic tool is presented in Table 2.3.5. The criteria are also derived by considering the concentration of total suspended solids, the type of tidal habitat (fresh, oligohaline, mesohaline, and polyhaline), and total water depth.

Table 2.3.5 Chlorophyll *a* concentrations (µg liter^{-1}) that reflect attainment of the Chesapeake Bay water clarity criteria for a given range of total suspended solids concentrations and shallow-water application depths. Areas in gray show where the water clarity criteria are exceeded. Source: USEPA (2003).

Total Suspended Solids (mg liter^{-1})	Tidal-Fresh and Oligohaline			Mesohaline and Polyhaline		
	Water-Column Depth (meters)					
	0.5 m	1 m	2 m	0.5 m	1 m	2 m
5	199	71	9	122	34	
10	171	43		95	8	
15	144	16		68		
20	116			42		

OPC Embayment Characteristics	Average Water Column Depth (m)	Average Total Suspended Solids (mg l^{-1})	Average Chlorophyll *a* concentration (µg liter^{-1})
	0.95 ± 0.004	26.07 ± 0.24	17.01 ± 0.22

Average values were calculated from a 7-year water quality monitoring data set 2002-2008 collected for OPC by the Chesapeake Bay National Estuarine Research Reserve in Maryland.

Considering the chlorophyll *a* criteria and OPC water quality information presented in Table 2.3.5, the conditions within the OPC embayment exceed the water quality criteria. This is particularly reflected by the high total suspended solid concentrations recorded for the area.

2.3.6.4. Nutrients

Highlights of the Bush River basin water quality status from 1950s to 1988 is provided as part of an analysis of data collected through different programs and organizations during that time period (Maryland DNR and Harford County 2002) including:

1972	Goucher College Environmental Studies Program had sampling stations in the open tidal waters of the Bush River and near the mouths of Bush Creek and Cranberry Run.
1977	Maryland Department of Natural Resources (MD-DNR) had sampling stations in the tidal waters of the Bush River.
1980-82	CH2M Hill, a consultant working for Harford County had most sampling stations in open tidal waters of the Bush River with the exception of two stations near the tidal interface in OPC and James Run.
1987	Harford County Department of Public Works.
1988	Harford Community College.

Some of their findings indicated high nutrient concentrations in the tidal Bush River, which tended to be accentuated by the slow flushing characteristics of the river. It typically takes 48 days for this tidal fresh estuary to flush. Overall, for total phosphorus, concentrations greater than 0.01 mg l^{-1} are considered high. Monitoring in 1972-73 by MD-DNR found that total phosphorus concentrations were nearly always greater than this benchmark with peak concentrations between 0.05 and 0.07 mg l^{-1} (MD-DNR and Harford County 2002).

For total inorganic nitrogen (which includes ammonia, nitrite and nitrate), concentrations greater than 0.5 to 1.5 mg l^{-1} were considered very high. Data from 1972-73 gathered by MD-DNR found inorganic nitrogen concentrations occasionally above 0.5 mg l^{-1}. Monitoring data found that ammonia nitrogen ranged from 0.01 to 0.11 mg l^{-1} and nitrate nitrogen ranged from 0.02 to 0.77 mg l^{-1} (MD-DNR and Harford County 2002).

Data collected during 1972 by the Goucher College Environmental Studies Program showed high nutrient concentrations near the mouths of Bush Creek and Cranberry Run. In 1987-1988, high nutrient concentrations were also found at the same and other sampling sites including Bynum Run, James Run, and Greys Run. Additionally, a trend toward increasing nitrate concentrations was reported.

A more recent water quality assessment (1989-2000) was conducted by the MD-DNR Resource Assessment Services Office using continuous data from a long-term water quality monitoring station located in the tidal Bush River, 39.4334º latitude, -76.2413º longitude (http://mddnr.chesapeakebay.net/bay_cond/bay_cond.cfm?param=bdo&station=WT11). A summary of their findings appears in the Table 2.3.6. The status for each parameter in the table is a relative ranking at three levels: good, fair and poor. For example, the ranking of “fair”, which is the most common ranking in the table, means that the Bush River ranking is fair compared to Chesapeake Bay tributaries with comparable salinity. The only two parameters that indicated a degrading trend were those of total phosphorus and algae abundance.

Table 2.3.6 Water quality status and trend analysis of the tidal Bush River (1985-2000) conducted by the Maryland DNR Resource Assessment Services Office.

Parameter	**Status 1998 -2000 data**	**Trend 1985 through 2000**
Nitrogen: total	Fair	No Trend
Phosphorus: total	Fair	Degrading (46%)
Algae: Abundance	Poor	Degrading (117%)
Dissolved Oxygen (summer, bottom waters)	Good	No Trend
Water Clarity: secchi depth	Poor	No Trend
Suspended Solids: total	Fair	No Trend

During 2002, a water quality assessment of the Bush River basin was conducted as part of the development of a Bush River watershed characterization to support the Harford County's Watershed Restoration Action Strategy (WRAS) for the River. The water quality assessment conducted was based on various water quality indicators including State 303(d) list impairment number, modeled total nitrogen (TN) load, modeled total phosphorus (TP) load, tidal habitat index, and tidal eutrophication index (Table 2.3.7; MD-DNR and Harford County 2002).

Table 2.3.7 Water quality assessment results for different drainage areas of the Bush River basin. Source: MD-DNR and Harford County (2002).

Water Quality Indicator	**Bush River**	**Lower Winters Run**	**Atkinson Reservoir**	**Bynum Run**	**Aberdeen Proving Ground**	**Swan Creek**
State 303(d) list impairment number	2	0	2	2	2	2
Modeled TN load	27.88	11.54	9.18	10.94	9.32	15.28
Modeled TP load	1.14	0.38	0.49	0.47	0.32	0.67
Tidal habitat index	4.3					
Tidal eutrophication index	7.0					

Notes:
Un-shaded indicators in the table mean that average watershed conditions measured by this indicator are better than the statewide benchmark.
Shaded indicators in the table mean that average watershed conditions measured by this indicator are worse than the statewide benchmark (i.e., water quality problems are more likely to arise due to the conditions represented by the indicator).

Results of the Bush River basin water quality assessment, particularly those regarding the nutrient indicators, showed that average conditions for the tidal Bush River has somewhat deteriorated compared to the previous analysis conducted by MD-DNR Resource Assessment

Services Office (Table 2.3.6). As shown in Table 2.3.7, both modeled TN and TP loads are higher than the statewide benchmark.

For the Lower Winters Run (which is one of the drainage areas of OPC; Figure 2.3.1), the total estimated nitrogen load seemed to be the main potential contributor to low water quality when compared to the other water quality indicators. According to this analysis the value estimated for total phosphorus was low and did not surpass the statewide benchmark (Table 2.3.7).

The latest trend (2002-2008) on nutrient concentrations is provided through the analysis of discrete water quality data collected by CBNERR-MD at six different stations within the OPC component (Table 2.3.8). Average total nitrogen (1.50 mg N l^{-1}) and total phosphorus (0.07 mg P l^{-1}) concentrations showed what is considered high values for this type of environment. This supports previous trends for the Bush River basin.

Table 2.3.8 Average nutrient concentrations in OPC. MPN, TPN, OPM, PPN, OPN, and Marina correspond to six long-term stations being monitored at this Reserve component (See Figure 2.3.21 for sites location).

OPC Station	PO_4 mg P l^{-1}	NO_2 mg N l^{-1}	NO_3 mg N l^{-1}	NH_4 mg N l^{-1}	Total P mg P l^{-1}	Total N mg N l^{-1}
MPN	0.0043	0.0157	0.8889	0.049	0.0615	1.539
se	0.0003	0.0012	0.0662	0.005	0.0029	0.058
TPN	0.0042	0.0153	1.1766	0.050	0.0612	1.747
se	0.0004	0.0010	0.0593	0.005	0.0055	0.056
OPM	0.0040	0.0126	0.8321	0.041	0.0664	1.530
se	0.0003	0.0010	0.0604	0.006	0.0037	0.054
PPN	0.0044	0.0128	0.5400	0.041	0.0718	1.358
se	0.0004	0.0013	0.0545	0.006	0.0037	0.051
OPN	0.0037	0.0123	0.5826	0.042	0.0667	1.360
se	0.0003	0.0011	0.0587	0.007	0.0032	0.053
Marina	0.0046	0.0105	0.5344	0.037	0.0782	1.465
se	0.0007	0.0010	0.0538	0.005	0.0035	0.048
Average	0.0042	0.0132	0.7591	0.043	0.0676	1.500
se	0.0001	0.0001	0.0018	0.0003	0.0004	0.0014

se = standard error
Average values were calculated based on data collected during the time period 2002-2008.
Values are not adjusted to reflect changes in river flow.

2.4 BIOLOGICAL AND ECOLOGICAL SETTING

2.4.1 Tidal Freshwater Marsh

The main portion of the OPC component consists of tidal freshwater marshes. Tidal freshwater marshes are a very distinctive type of ecosystem located upstream from tidal saline wetlands and downstream from non-tidal freshwater wetlands (Odum et al. 1984). These ecosystems are characterized by near freshwater conditions (average annual salinity is about 0.5 ppt or lower except during periods of prolonged drought conditions); plant and animal communities dominated by freshwater species; and the influence of diurnal tides. Based on salinity, tidal freshwater marshes are located between the oligohaline and non tidal freshwater zones of the estuary (Figure 2.4.1; Odum et al. 1984).

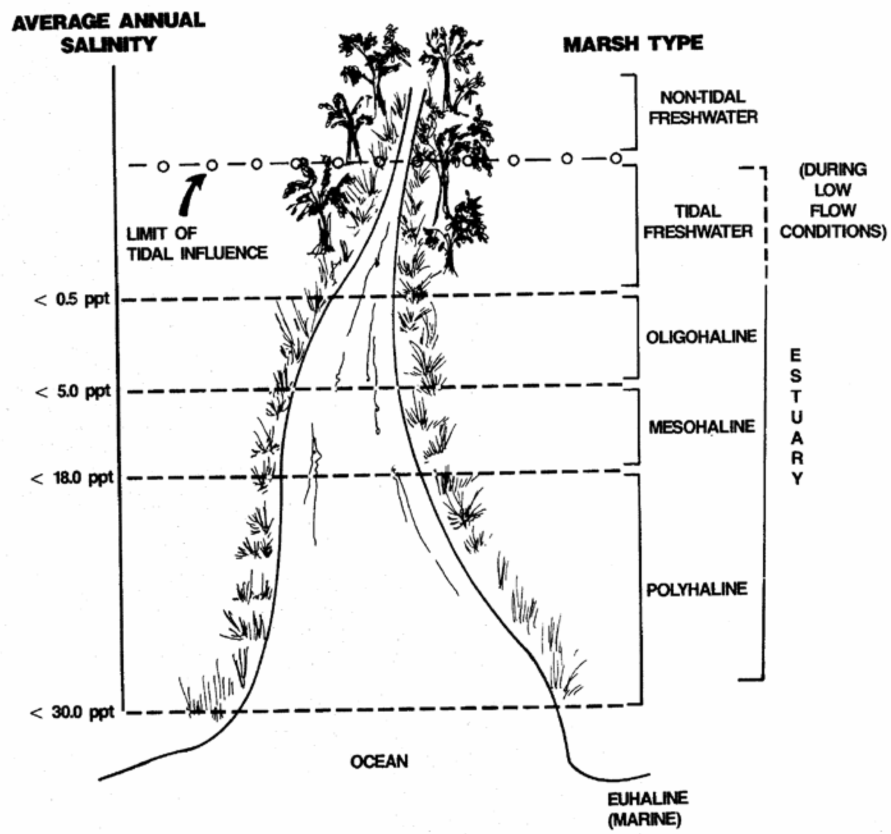


Figure 2.4.1 Relationship between marsh type and average annual salinity (values are approximate only). Source: Odum et al. (1984).

Tidal freshwater marshes are characterized by higher species diversity than higher salinity estuarine marshes and it is dominated by broad-leafed plants, grasses, rushes, shrubs, and herbaceous plants. The lack of estuarine marsh grasses such as *Spartina spp*. is what differentiates these ecosystems from oligohaline and higher salinity marshes (Odum et al. 1984). The development of extensive tidal freshwater marshes is favored by a major influx of freshwater, daily tidal amplitude of at least 0.5 m, and a geomorphological structure that constricts and magnifies the tidal wave in the upstream portion of the estuary (Odum et al. 1984).

Tidal freshwater marshes are dynamic environments and can change spatially and temporarily in response to climatic conditions, hydrology, and other natural and anthropogenic stressors. The functioning of the ecosystem depends on the fluxes of water, sediment, nutrients and energy from the watershed. At the OPC component, nutrients and energy are exchanged with the tidal portion of the Bush River and the Chesapeake Bay.

Evidence from historical maps and aerial photography show a significant expansion in the extent of the marsh even in the face of rising sea levels. The source of this expansion of the wetland is eroded upland sediments. The removal and redeposition of sediment has been occurring since the end of the pleistocene glaciation, but the past few decades have witnessed an acceleration of marsh building coinciding with the clearing of forest and with the conversion of farmland for housing development. Because OPC is dominated by the flow of Winters Run and to a lesser extent HaHa Branch, any activity in these watersheds influences what happens in the estuary. Land use changes in the watershed can have a significant cumulative impact on the estuary (Copeland et al. 1983). Studies by the University of Maryland (ICPRB, 1991) have documented a six fold increase in sediment loadings in coastal plain streams as the predominant land use shifted from agricultural to residential. The OPC marsh would probably have expanded even more had not a substantial portion of the sediment load in Winters Run deposited behind the upstream dams which have significantly filled in.

In studies of similar freshwater marshes in South River, Anne Arundel County, mass vertical accretion rates ranging from 4.7 mm yr^{-1} to 8.1 mm yr^{-1} (0.19 in. yr^{-1} to 0.32 in. yr^{-1}) were measured relative to local sea level. Local sea level rise has been estimated at about 3 mm yr^{-1} (0.12 in. yr^{-1}); (Stevenson et al. 1986) indicating that gross deposition rates were probably more around 8 to 12 mm yr^{-1} (0.31 to 0.47 in. yr^{-1}). Historic sedimentation rates measured by coring studies in nearby Furnace Bay (Brush 1990) documented sedimentation rates ranging from 7.2 to 12.0 mm yr^{-1}(0.28 to 0.47 yr^{-1}). Thus the growth of the OPC marsh can be considered fairly typical of subtidal accretion in the upper bay, western shore region. The Anacostia River, draining the edge of the Piedmont Plateau has accumulated a minimum of 12.2 vertical meters (40 vertical feet) of sediment in its flood plain over the last 200 years.

Most of the shore line retreat in the upper Chesapeake Bay and tidal tributaries currently ascribed to sea level rise is the result of eroding slopes not from loss of marsh. The emergent vegetation of the freshwater marshes does provide some accumulation of organic matter, but in this system the accumulation of inorganic sediment from the watershed predominates. The result is a marsh substrate with a lower proportion of organic matter than the typical *Spartina* marsh where biomass accumulation and anoxic sediments are characteristic.

The rate of export of organic carbon, nitrogen, and phosphorous from the marsh has not been systematically studied for the OPC marsh. However, studies of a similar tidal fresh water marsh at the Jug Bay Reserve component have shown that the low marsh is not a net importer of organic carbon or inorganic nutrients (N and P), but the high marsh is (Kahn & Brush, 1991). Several hypotheses have been proposed to explain this finding including differences in decomposition and nutrient cycling pathways and the possibility that organic enrichment affects the nutrient retention of marsh soils by removing any pre-existing nutrient limitations on plant growth or that increases in the quantities of iron (Fe), aluminum (Al) and magnesium (Mn) oxides in the sediment from upland erosion have increased the ability of the marsh sediments to bind phosphorus. At present, it appears that the primary source of nutrient loadings into OPC Reserve waters derive from non-point sources.

Tidal freshwater marshes contain a high diversity of plant species arranged as vegetation zones along an elevation gradient. These zones, however, are not as well defined as those found in salt marshes. Each zone is characterized by one or two dominant species (Mitsch and Gosselink 2000, Pasternack et al. 2000, Leck and Simpson 1995, Simpson et al. 1983). Elevation and hydrology are the primary factors controlling plant distribution patterns and associations in tidal freshwater marshes as they dictate the depth and duration of flooding within the wetland community (Mitch and Gosselink 2000, Pasternack et al. 2000). Therefore, any factor or disturbance producing a change in elevation and hydrology, either by increasing or decreasing the substrate level or by altering the hydrologic regime, will affect species composition (Leck and Simpson 1987, Niering 1989, Leck and Simpson 1995, Pasternack et al 2000). Although biotic or internal factors may be important in altering the substrate and initiating habitat change in coastal wetlands, most evidence supports the role of abiotic or external factors, such as shifts in sediment or hydrology by storms (Niering and Warren 1980; Serodes and Troude 1984, Clark and Patterson 1985, Clark 1986, Shaffer et al. 1992, Mitsch and Gosselink 2000).

According to Hilgartner (1995) and Pasternack et al. (2000) OPC Reserve wetlands include a mosaic of one subtidal and eight intertidal/supratidal habitat zones occurring in general along a gradient of increasing elevation and decreasing flood levels. The subtidal habitat is generally dominated by submerged aquatic vegetation during the growing season with some patches of barren sediment. The intertidal and supratidal habitats and their relative elevation levels above sea level include pioneer mudlflat (0 m), floating leaf (0 m), low marsh (<0.3 m or <0.98 ft.), middle marsh (0.3-0.6 m or 0.98-2.0 ft.), high marsh (1.0 m or 3.3 ft), shrub marsh (2.0-3.0 m or 6.6-9.8 ft.), shrub levee (1.0-3.0 m or 3.3-9.8 ft.), and riparian forest (>3.0 m or >9.8 ft.). Distinction among these different habitats is not always evident in tidal freshwater marshes as their presence is more a response to particular elevation and hydrological characteristics (Leck et al. 2009). Gradation from middle to high marsh is often subtle and almost imperceptible. Because of this and for the purpose of this document we have opted for recognizing mainly one subtidal and five intertidal/supratidal habitats in tidal freshwater marshes based in hydroperiod: 1) subtidal and open water; 2) pioneer mudflat; 3) low marsh; 4) middle-high marsh; 5) scrub-shrub swamp; and 6) swamp or riparian forest. These predominant habitats will be described below and specific information about OPC will be based in the studies conducted by Hilgartner (1995) and Pasternack et al. (2000) as well as current CBNERR-MD monitoring efforts of emergent and submerged aquatic vegetation.

2.4.1.1 Subtidal and open water

One of the most important communities found in the subtidal zone of the OPC component is submerged aquatic vegetation (SAV) or underwater grasses. These are non-flowering or flowering macrophytes that grow completely underwater; their growing season extends from April to October. When not colonized by SAV this subtidal and open water zone is dominated by barren sediment composed mainly of silt. Spatial variation of sediment texture, however, changes from gravel to clay.

Underwater grasses provide important ecological functions, including: habitat for fish, supply food for aquatic organisms and waterfowl, enhance nutrient accumulation, transformation, and cycling; promotes particle trapping and help stabilize bottom sediments (Lubbers et al. 1990, Caffrey and Kemp 1992, Rybicki et al. 1997). A historical review from the Virginia Institute of Marine Science (http://web.vims.edu/bio/sav/index.html) has indicated that little SAV was found in the Bush River before 1996. Underwater grasses began to reappear in the Bush River in 1996 and have maintained a constant presence since then (Figure 2.4.2), although the community' species composition and dominance has changed through time.

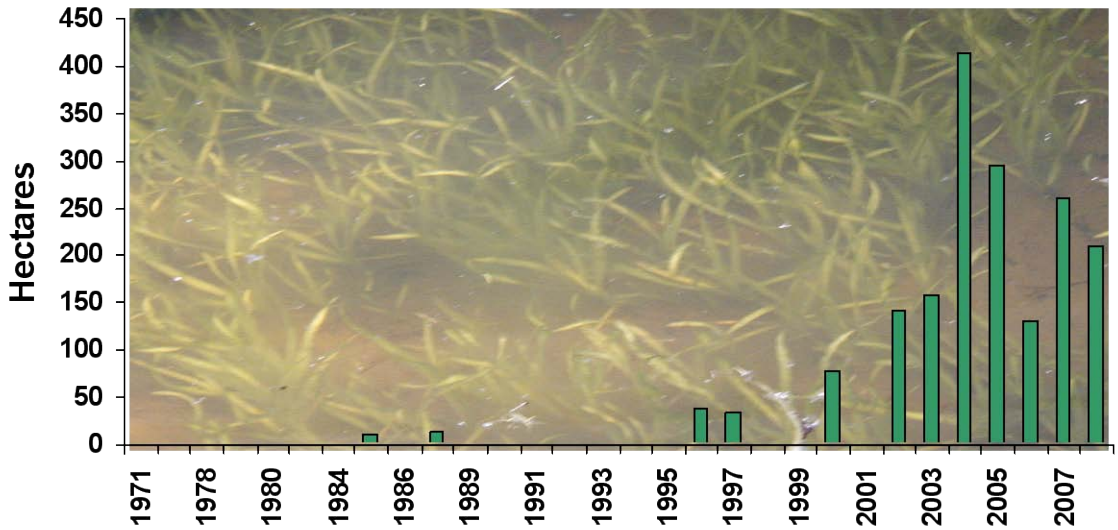


Figure 2.4.2 Long-term distribution of submerged aquatic vegetation in the Bush River (1971-2008). No value indicates that the area was not mapped or not fully mapped. Data source: Virginia Institute of Marine Science.

From 2000 to 2004, the SAV coverage in the Bush River steadily increased from 79 to 414 hectares (195.2 to 1023 acres). During this time, SAV beds were concentrated in the upper reaches of Church Creek, OPC, and Dove Cove. SAV coverage expanded by 162% between 2003 and 2004 and additional beds were observed along the main stem of the Bush River. Underwater grasses reached their highest level in the Bush River in 2004; declined during 2005 and 2006, but increased in 2007 to then show a small decline again in 2008. The decline in SAV during 2004-2006 coincided with the Bush River failing to meet several important SAV habitat criteria. These criteria were formulated from a three year water quality assessment which accounts for yearly variability in hydrographic conditions including precipitation and river inflow. From 2004 to 2006, the Bush River met the SAV criteria for phosphorus, but failed to meet criteria for water clarity and chlorophyll (algae), and was marginal for total suspended solids (TSS) concentrations (Trice et al. 2007).

The growth of different species within the upper reaches of the Chesapeake Bay depends on tolerances to different environmental conditions including salinity, light, temperature, nutrients levels, sediment type, and physical setting. During the 2004 peak of historical SAV growth a total of ten species were observed in the Bush River, which included: *Ceratophyllum demersum* (coontail), *Elodea canadensis* (common waterweed), *Heteranthera dubia* (water stargrass), *Hydrilla verticillata* (hydrilla – non native), *Myriophyllum spicatum* (eurasian watermilfoil – non native), *Najas guadalupensis* (southern naiad), *Najas minor* (spiny naiad – non native), *Potamogeton* pusillus (slender pondweed), *Vallisneria americana* (wild celery), and *Zannichellia palustris* (horned pondweed; Orth et al. 2004).

By 2008-2009, a total of seven species are still reported to occur in the Bush River-OPC area including *H. verticillata, M. spicatum, C. demersum, V. americana, Z. palustris, P. pusillus*, and *E. canadensis*. *H. verticillata* currently is the most abundant and has the widest distribution of any of the SAV species within the component. The capability of this species to grow well in a wide range of environmental conditions makes it a great competitor. *H. verticillata* can be found under oligotrophic (low nutrients) or eutrophic (high nutrients) conditions (Cook and Luond 1982), at salinities ranging from freshwater to close to that of sea water (Haller et al. 1974, Steward and Van 1987), in bodies of water with widely ranging pH levels (Steward 1991), and it grows well under low light levels (1% of full sunlight or less; Van et al. 1976). *H. verticillata* can grow up to 2.5 cm per day, allowing quick growth to the water surface and the development of a canopy; this canopy then shades out other SAV species (Langeland 1996, Haller and Sutton 1975; Figure 2.4.3).

Photo credit: J. Bortz

Figure 2.4.3 Extensive "*H. verticillata* mat" at OPC. An example of canopy development and potential overshadowing of other underwater grass species.

Monospecific stands of *H. verticillata* can provide some habitat for fish and other wildlife, as well as food for waterfowl (Esler 1989, Colle et al. 1987). *H. verticillata* will also tend to increase water clarity (Canfield et al. 1984), which is probably due to a reduction of sediment re-suspension and reduction of phytoplankton populations by nutrient uptake. However, when *H. verticillata* mats start reaching more than 30% to 40% of the area, the benefits provided start to diminish. Water quality starts to decrease by raising pH, decreasing oxygen under the mats, and increasing temperature, which decreases its habitat value for fish and other aquatic organisms. Additionally, extensive *H. verticillata* mats tend to outcompete native underwater grass communities and impact water use by interfering with navigation of both recreational and commercial craft.

Although the benefits and impacts of *H. verticillata* have not been directly measured at the OPC Reserve, observations support most of the statements indicated above. For example, during recent years *H. verticillata* has often covered, during the growing season (April – October), much of the open water embayment at OPC highly limiting the recreational use of the area by canoes and small boats (Figure 2.4.3). Water quality also seems to change during this time of the year. For example, data recorded from 2004 through the CBNERR-MD's continuous water quality monitoring station at OPC shows a decline of oxygen levels between July and September, which coincides with the peak of SAV growth, particularly the dominant *H. verticillata*; similarly, pH levels slightly increase between June and August (Figure 2.4.4). Similar patterns were observed for other years.

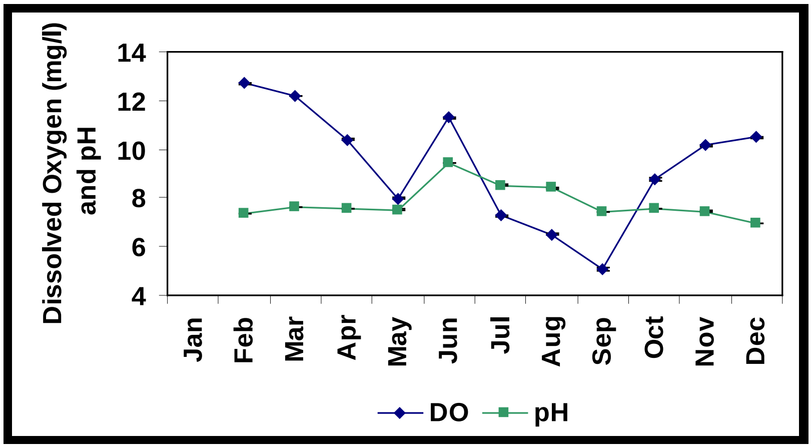


Figure 2.4.4 Dissolved oxygen (DO) and pH levels during 2004 in OPC. Submerged aquatic vegetation growing season extends from April to October.

In an effort to monitor the status and spatial and temporal changes of the SAV community at the OPC component, the CBNERR-MD research program established in 2007 a monitoring effort that involves the yearly sampling of five main SAV beds within the Bush River and OPC. Within each site, a 60 m-long (197 ft.) transect is sampled for SAV at 10 m (32.8 ft.) intervals (three times a year: June-August-October) using modified oyster tongs. Data collected include dissolved oxygen, temperature, salinity, conductivity, secchi depth, water depth, qualitative description of substrate type, species presence, and an indirect measure of species biomass. Collected data are recorded and organized by CBNERR-MD and are available upon request.

Considering that the OPC SAV community is dominated by the non-native *H. verticillata*, various efforts have been conducted to attempt the restoration of some of the native species through different volunteer and local community efforts. Some of these efforts include the Chesapeake Bay Foundation's Grasses for the Masses Program, which is organized in OPC through the Anita Leight Estuary Center and CBNERR-MD. This program involves the participation of students, volunteers, and the local community in the growing and planting of native underwater grasses including *V. americana*, and *H. dubia*. These grasses are planted in May and June in locations where *H. verticillata* is either not present or minimal. *V. americana* seeds are also spread during May and June to allow germination of the seeds prior to *H. verticillata* forming dense mats.

Examples of additional SAV restoration activities that have taken place at the OPC Reserve include the planting of *V. americana* in 2003 through a collaborative effort among the Chesapeake Bay Foundation and its BaySaver volunteers, the National Oceanic and Atmospheric Administration (NOAA), and Maryland DNR including CBNERR-MD staff. This effort was conducted as part of the Chesapeake Bay Program strategy to restore SAV within the Chesapeake Bay, and involved a study to determine the effectiveness of using machine plantings to restore SAV (Bergstrom et al. 2004). Other plantings in OPC were conducted as part of the 2009 NOAA Restoration Day (Figure 2.4.5). As part of this activity NOAA staff grow SAV in small tanks, which are then planted during one-day field restoration event (more information about this event could be found at: http://restorationday.noaa.gov/).

Despite all SAV plantings to increase the presence of native species in OPC, the dominance of the non-native *H. verticillata* is still evident. Monitoring of some of these restoration efforts have shown limited success, which could be attributed to different factors including competition with non-native species and inadequate habitat conditions, particularly due to high water turbidity within this area. The success of these planting events, however, resides in the outreach and education value as it creates community awareness of the importance of SAV for the health of the Chesapeake Bay and its aquatic resources.

Photo credits: J. Bortz

Figure 2.4.5 Underwater grass restoration event in OPC: 2004 grasses for the masses (left) and 2009 NOAA Restoration Day (right).

2.4.1.2 Pioneer mudflat

The mudflat area in OPC becomes exposed only during low tide. Mudflat acreage has increased through the years as a result of high sedimentation rates particularly at the mouth of the HaHa Branch (Figure 2.4.6). As sediments are deposited, surface elevation increases leading to a decrease in flooding frequency and duration, which eventually allows for plant colonization. This growing mudflat by the HaHa Branch is currently being colonized by several pioneer species (Table 2.4.1), which were recorded after a preliminary survey conducted during the fall of 2009. From the species listed in Table 2.4.1, hooded arrow-head (*Sagittaria calycina* var. *spongiosa*) was particularly abundant in this mudflat. More information on the progression of this mudflat colonization needs be conducted to better understand this dynamic environment.

Table 2.4.1 Pioneer species colonizing a mudflat by the mouth of the HaHa Branch at OPC.

Scientific Name	Common Name
Sagittaria calycina var. spongiosa	Spongy arrow-head
Peltandra virginica	Arrow arum
Sagittaria latifolia	Arrowhead
Pontederia cordata	Pickerelweed
Acorus calamus	Sweet flag
Zizania aquatica	Wild rice
Ludwigia palustris	Water purslane
Heteranthera reniformis	Mud plantain
Polygonum punctatum	Smartweed
Thypha latifolia	Broadleaf cattail
Bidens tripartita	Beggar-ticks
	Four grass/sedge species

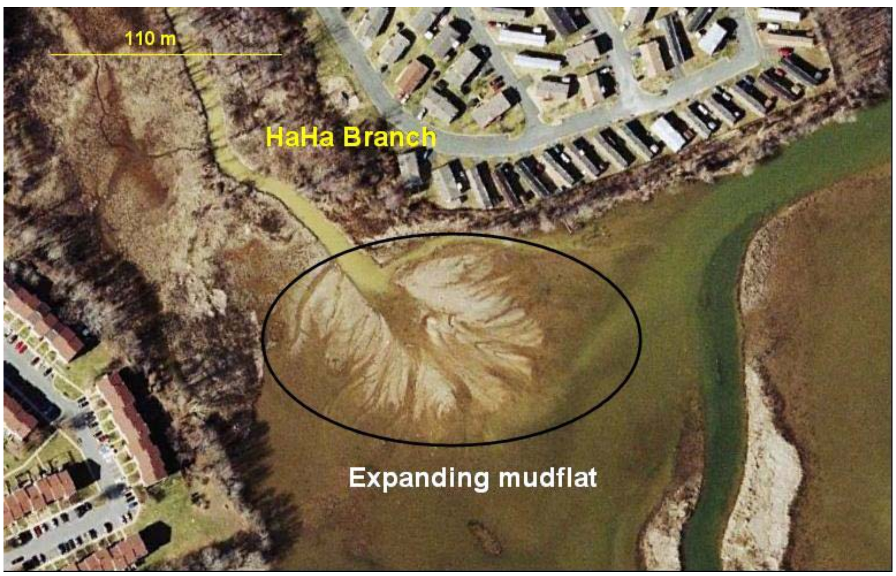


Figure 2.4.6 Aerial image of HaHa Branch showing a sediment plume been delivered into the OPC estuary.

2.4.1.3 Low marsh

The OPC low marsh is a very dynamic environment, characterized by longer inundation periods than the middle-high marsh and often colonized by perennial species (Leck et al. 2009). Perennial plants grow during spring and summer and die back during the winter leaving vast expanses of apparently unvegetated mud. In OPC, as a result of sedimentary processes, the low marsh is expanding downstream from the distributaries of OPC into the Bush River, particularly around the HaHa Branch discharge zone (see section 2.4.1.2 - pioneer mudflat, above).

The area of low marsh in OPC comprises about 13.4 hectares (33 acres) and is mainly dominated by the broad-leaved, perennial, fleshy species *Nufar lutea* (spatterdock). In some areas, submerged macrophytes (i.e., *H. verticillata*) can be found growing among the *N. lutea* plants. *N. lutea* covers extensive areas during the growing season, which appear from the air as large ring shaped structures. *N. lutea* stores its seasonal productivity in massive underground rhizomes which fuel rapid growth in the spring when water temperatures rise. During the winter, exposed frozen mud flats develop a distinctly lumpy appearance from the spatterdock rhizomes below the surface.

Progressing inland and/or among the *N. lutea* rings other species also found in the low marsh may include *Pontederia cordata* (pickerelweed), *Zizania aquatica* (wild rice), *Peltandra virginica* (arrow arum), and *Sagittaria latifolia* (big leaved arrow head). These, however, often grow in low densities in this low marsh area.

In the low marsh small fish, primarily *Fundulus heteroclitus* (mummichogs) forage among the stems and submerged leaves and in turn are fed on by *Sterna spp*. (terns) and *Ceryle alcyon* (belted kingfishers). *C. alcyon* frequent the forest edge of the marsh while the terns fish the open water edge. Among the *N. lutea* low marsh zone is also common to observe the *Cyprinus carpio* (common carp) swimming and searching for food.

2.4.1.4 Middle – high marsh

Low and middle-high marsh together comprise about 36% (35.6 hectares or 88 acres) of the wetland area in OPC (Mause, 1986). The middle-high marsh zone is characterized by a mosaic of species (both perennials and annuals), which diversity is higher than that found in the low marsh zone. Species distribution within this zone is determined by various physical and biotic factors/stressors (including flooding, soil conditions, disturbance, and competition) and by how individual species tolerate or respond to these stressors, which may relate to seed banks, germination capacity, growth rate, etc. In contrast with the low marsh zone where physical stressors are more important (i.e. inundation), in the middle – high marsh zone competition plays a dominant role (Leck et al. 2009). Because of the intrinsic environmental variability of this zone and the higher species diversity, it is not uncommon to find diverse patches interspersed with various sizes of almost pure monospecific patches of species such as *Typha spp*. and *Acoraus calamus*.

Species presence and distribution within tidal freshwater marshes varies not only spatially but also seasonally, between years, and over longer temporal scales. Some of this variability could be attributed to the presence of annual and perennial species, which results in a complex dynamics of plants growing, flowering, producing fruit, and dying back at different times throughout the growing season (Leck et al. 2009). Inter-annual and long-term variability is linked to a variety of environmental and biotic factors including climatic conditions; soil and sedimentation characteristics; hydrology; natural and anthropogenic-induced habitat changes; species seed production and germination success, etc. (Leck et al. 2009).

Some of the dominant species found in the middle-high zone of the OPC marsh include *Typha angustifolia* (narrow leaf cattail), *Impatiens capensis* (jewelweed), *Leersia oryzoides* (rice cutgrass), and *Acoraus calamus* (sweet flag). *Peltandra virginica* (arrow-arum) is found in this zone and throughout the marsh (Figure 2.4.7). Other species were found in limited areas such as *Orontium* *aquaticum*, which occurred only in one section of marsh in HaHa Branch. *Cephalanthus occidentalis* (button bush) and *Cornus amomum* (silky dogwood) appear at the transition zone to the wooded wetland or swamp. *Betula nigra* (river birch), *C. amomum* and *Toxicodendron radicans* (poison ivy) line the channels of OPC and Winters Run which flow through the wetland.

Lobelia cardinalis (cardinal flower) and *Campsis radicans* (trumpet-vine) growing in the high marsh serve as food sources for the *Archilochus colubris* (ruby-throated humming bird). *Eupatoriadelphus maculatus* (spotted trumpetweed) and other large flowers in this region form an important food source for butterflies and insects of the order Hymenoptera.

An extended list of plant species found within the OPC marsh and swamp habitats is given in Appendix I. This list will continually be updated as more research and monitoring is conducted in the OPC reserve. As indicated in previous sections tidal freshwater marshes are characterized for their great biodiversity. During the 1990s Hilgartner (1995) identified 109 species in OPC recorded from transect and quadrant analysis. Seventy-five species (68.8%) were herbaceous and 34 (31.2%) arboreal. A continuation of monitoring into 2004 by Hilgartner and Pasternack, Hilgartner and Brush (2000) provided a total list of 177 species. Of these 138 (78%) are herbaceous and 39 (22%) are woody or arboreal.

As part of the CBNERR-MD research and monitoring program, the emergent vegetation of OPC tidal freshwater marshes have been monitored since 2008 using protocols established for the NERR System (Moore 2009). The long-term goal of this monitoring effort is to characterize this marsh community and determine changes in response to land use and climate change. Preliminary results show, as indicated previously, an overall dominance of *N. lutea* in the low marsh zone and *T. angustifolia* and *P. virginica* in the middle-high marsh. This data also highlights the natural variability within the system, which is mainly expressed by differences in the presence and abundance of the less dominant species (Figure 2.4.7).

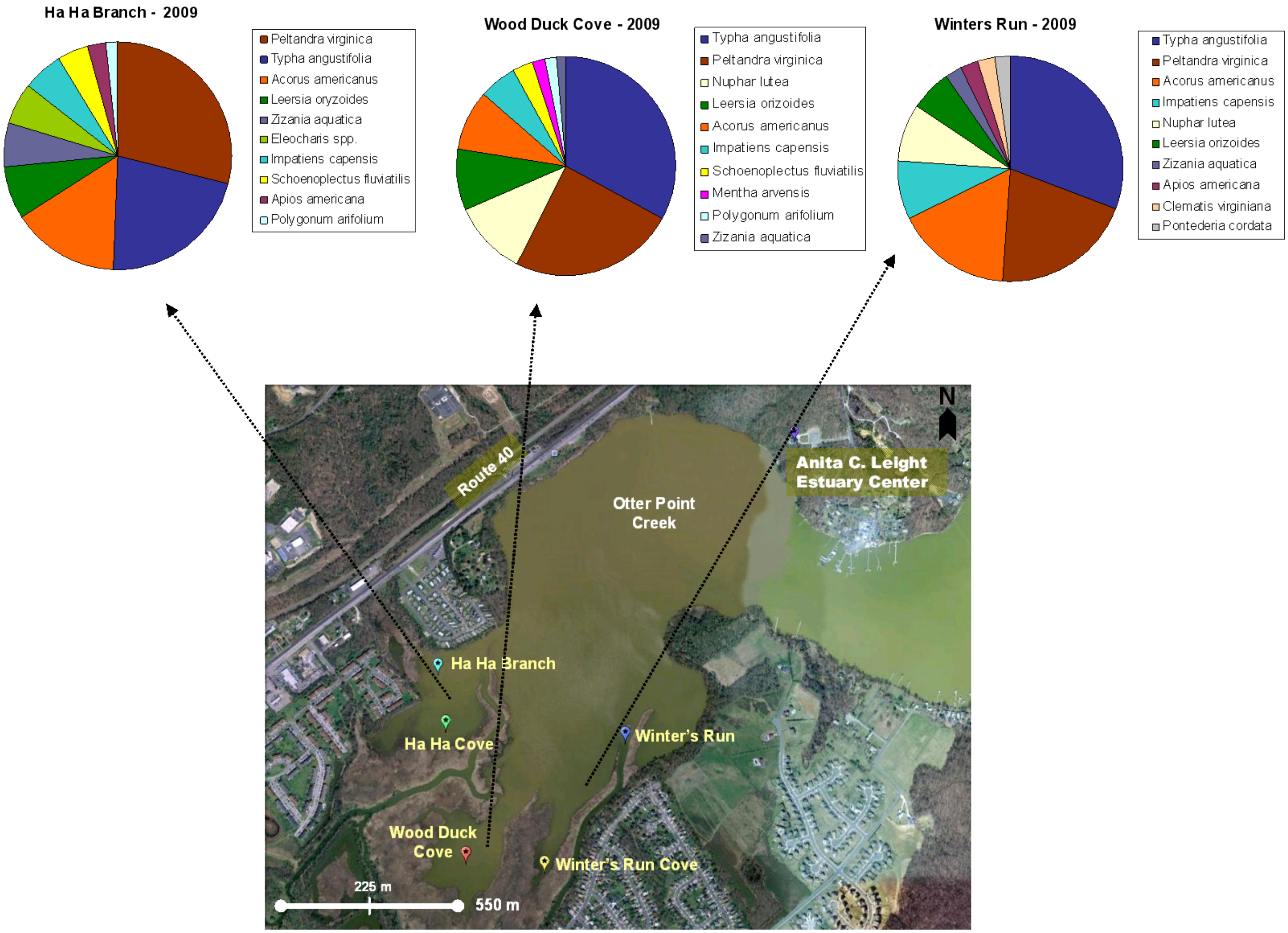


Figure 2.4.7 Representation of the ten dominant species found along transects located in three main areas of the OPC tidal freshwater marsh: a) HaHa Branch, b) Wood Duck Cove, and c) Winters Run.

2.4.1.5 Scrub - shrub swamp

Species found within the scrub-shrub marsh area include *Typha latifolia* (broad leaf cattail), *Salix nigra* (black willow), and *Saururus cernuus* (lizard's tail). Shrub levee species include *Cornus amomum* (silky dogwood), *Alnus serrulata* (common alder), and *Polygonum sagittatum* (arrowleaf tearthumb). The abundance of woody perennial shrubs in the high marsh provides a variety of habitats for birds and insects.

2.4.1.6 Riparian forest or swamp

A deciduous riparian hardwood forest dominates much of the OPC component. This vegetation is adapted to a floodplain environment where small, bifurcated tidal stream channels meander throughout, depositing alluvial silt and sand sediment. There is an intimate relationship between the river and the floodplain where a continual dynamic balance exists between deposition and removal of sediment. Subtle changes in elevation above the water table and the proximity to channels can affect zonation of vegetation. Plants adapted to this environment must be able to withstand periods of flooding and saturation of the roots when soil becomes anaerobic. Various species are adapted to different flooding frequencies and duration, so the composition of the vegetation is closely dependant on elevation and hydroperiod. In addition, asexual reproduction by rhizomes and stolons combined with the production of abundant seeds dispersed by the wind, water or both permit these species to be particularly well adapted to establishment and growth in wetlands continually subjected to disturbance (Hupp and Simon 1991, Harlow and Harrar 1969).

Natural disturbances commonly include periodic flooding above stream banks by storms and hurricanes. Other natural disturbances are created by beavers which have periodically inhabited the component and flooded portions behind their dams. Anthropogenic disturbances have included the building of roads, principally U.S. Route 40 and the construction of sewer lines thorough the area, the temporary sewage oxidation ponds, and storm water runoff draining from adjacent high density townhouse development into the riparian forest.

The forest canopy moderates water temperatures in the stream by shading the surface during the summer and permitting sunlight to reach the water surface during the colder winter months. Tree roots increase bank stability and create overhanging cover for aquatic animals. Leaf fall seasonally adds organic matter to the stream and fallen trunks and branches retard stream flow creating riffles and pools. The coarse woody debris becomes a substrate for microscopic biological activity. The current velocity is moderately high in the upper portion of Winters Run except for the pools formed behind log jams. The substrate of these rivers is predominately coarse sand and gravel. There is no significant submerged aquatic vegetation in this portion of the river.

In riparian wetlands stem density is greatest within the first few years of establishment, then declines with stand age as the canopy closes and competition for light and root space intensifies (Haupp and Simon, 1991; others). The tidal riparian forest or swamp habitat is dominated by *Acer negundo* (box elder) and its codominants, *Fraxinus pennsylvanica* (green ash) and *Betula nigra* (river birch). This is an association that is also found along numerous non-tidal riparian systems in the region (Brush et al 1980). The riparian forest sampled in the OPC component showed a mean relative density of 55.1 % and 22.2 % for *A. negundo* and *F. pennsylvanica*, respectively.

Scattered throughout the forest and more common along the river banks are *Platanus occidentalis* (sycamore), *Salix nigra* (black willow), *Betula nigra* (river birch), *Acer saccharinum* (silver maple), *Carva cordiformis* (butternut), and *Liquidambar styraciflua* (sweetgum), which are indicatives of long periods of soil saturation. This successional community will persist until further fluvial deposition creates improved soil drainage. These species occur as dominant species in seasonally flooded riparian wetlands throughout the southern U.S. and are typical of a hydrologic regime where the annual flooding frequency is 51 to 100 % and where the duration of flooding is 12.5% to 25 % of the growing season (Mitsch and Gosselink 1986). *B. nigra* and *S. nigra* are species typical of initial revegetation stages in early succession of riparian wetland vegetation. *A. negundo* is typical of initial revegetation stages where bank accretion is occurring during channel evolution, while *F. pennsylvanica* is typical of more stable river stages when accretion rates decline (Haupp and Simon 1991).

Succession would then move the community toward *Acer rubrum* (red maple) and *Liriodendron tulipifera* (tulip poplar) as dominant species. The mature trees in the riparian forest community are estimated to be between 40 and 60 years old. A few individual *P. occidentalis*, *S. nigra* and *B. nigra* have diameters at breast height (DBH) of 0.50 meters or more (W. Hillgartner, personal communication). These trees are generally scattered, particularly along the river bank. No exceptionally old trees have been observed in the Reserve. Although the OPC Reserve is within the limits of the Southern Forest Region it is close enough to the northern limit that *Taxodium distichum* (bald cypress) will not naturally establish.

There has been continual disturbance of the forest by hydrologic and human factors and some sections of the forest became established relatively recently. Aerial photography from 1957 clearly shows open unforested areas around Route 40 and other areas. In a 1967 aerial photograph, these areas show trees moving in and by 1986 the same areas have a closed canopy forest which remains through the present. Other sections of former riparian forest have reverted to open habitats. The south bank of Winters Run at Route 40 was flooded after Hurricane Agnes in 1972. The area today remains a cattail marsh peppered with dead tree trunks and sprouting black willow. New stream channels, circumventing the log jams have appeared and have altered the forest composition in this region.

The unevenness of the ground, a series of levees and swales indicate long term meandering of the river channel with the resulting sorting and reorganizing of the substrate. On top of this is grafted the anthropogenic disturbances to the soil associated with the building of roads (U.S. Route 40) sewer lines and ponds. The adjacent high density townhouse development drains storm water runoff directly into the riparian forest. Ground cover in the region of the Rt. 40 crossing is dominated by *Poa sp*. (grass), *Viola papilionacea* (violet), *Urtica dioica* (stinging nettle), *Impatiens capensis* (jewelweed), *Polygonum punctatum* (dotted smartweed), *Rudbeckia laciniata* (green-headed coneflower), and *Toxicodendron radicans* (poison ivy). Other less common species also found in this area are *Commelina sp*. (dayflower), *Saururus cernuus* (lizard tail), *Tovara virginiana* (jumpseed), and *Osmorhiza claytoni* (sweet cicely). Several introduced species dominate portions of the ground cover including two rapid growing vines: *Lonicera japonica* (Japanese honeysuckle) and *Celastrus orbiculatus* (Asian bittersweet). In some areas the introduced *Glechoma hederacea* (ground ivy) is extensive indication that the area may have been open or park like not too long ago. This species is on slightly higher ground where flooding appears to occur less frequently. The *C. orbiculatus* is common on trees along the river bank and forms a virtually impenetrable thicket in some locations.

At least 10 tree species are known to occur in this region, 31 herbaceous plants, and an undetermined number of grasses. Three of the six most commonly encountered species are introduced: *L. japonica*, *C. orbiculatus* and *Polygonum perfoliatum* (Asiatic tearthumb). Two other species of tearthumb, both native are also present in the riparian forest. *Lindera benzoin* (spice bush), *Glechoma hederacea* (ground ivy), *Viola papilionacea* (wood violets), and various grasses are also dominant understory herbs in this community.

2.4.1.7 Other estuarine habitats

Lagoons

Moving from the riparian forest toward the open water, one encounters high steep berms which surround poorly flushed ponds or lagoons. These lagoons are tidally influenced, extremely shallow, and nearly filled with emergent vegetation. Except for the presence of the berm surrounding them, the lagoons are virtually indistinguishable from the marsh beyond. In most places the vegetation is submerged only at the highest tides. Broad leaved cattails form the predominant vegetation in the interior of the ponds although some wild rice grows there as well. The perimeter of the lagoons remains submerged at all normal tide stages and do support some watermilfoil. The berms around these ponds support *Cephalanthus occidentalis* (button bush), *Cornus amomum* (silky dogwood), *Eupatoriadelphus maculatus* (spotted trumpetweed) and other shrubs which provide significant "edge" effect for wildlife habitat. The shrubs along the berms attract *Archilochus colubris* (ruby-throated hummingbird) and a variety of butterfly species. Fish species found in the ponds include the *Fundulus diaphanus* (banded killifish), *Ictalurus nebulosus* (brown bullhead), *Ictalurus punctatus* (channel catfish), and *Cyprinus carpio* (common carp). The sediment in the ponds is highly organic and derives from nearly a decade of use as oxidation lagoons for excess sewage.

The two lagoons were constructed and started operation around 1968 to serve the residential development which began in the early 1960's. By the mid 1960's Edgewood Meadows housing development had encroached close to the stream bank at Winters Run. The Edgewood Heights housing development occurred during this time also. Both lagoons were abandoned when a collector line to the Bill Bass pumping station was completed; this line was constructed across Winters Run and bisects the Reserve component. By 1986 marsh vegetation had completely recolonized the abandoned lagoons. The year that the berms were breached and opened to tidal flushing was not recorded but probably occurred during Hurricane Agnes in 1972 when the entire region was inundated.

The lagoon area is managed by the Isaac Walton League for the production of *Anas platyrhynchos* (mallard). Wire duck nests are mounted on poles in the cattail beds and filled with hay to provide food and cover for the nesting hens. The state rare black duck also nests in this area. However the Izaak Walton League makes no special nesting structures for *Anas rubripes* (black duck) which competitively interacts with *A. platyrhynchos*.

The area of the excavation for the placement of the Bill Pass line now supports stands of the *Phragmites australis* (common reed), an opportunistic invader of disturbed hydric soils. The patches of common reed are being monitored for potential spread beyond the region of disturbed soils and a control plan would be developed in the event that the plant does become a problem.

Snake Island

A significant feature of OPC is Snake Island, the only visible remains of what old maps show as a series of islands in open water. Sea level change and erosion have reduced the size of the islands. Sediment deposition from the upper watershed has fostered the expansion of the marsh until it has surrounded the remains of the island to the point where it appears to be just a wooded hummock 35 meters wide surrounded by low marsh vegetation.

In terms of vegetation, Snake Island consists in a mesophytic forest. The higher elevation (6 m above sea level) permits better drainage of the soil. The dominant vegetation include *Sassafras albidum* (sassafras), *Vaccinium corybosum* (blueberry), *Quercus falcata* (southern red oak), and *Pinus rigida* (pitch pine). *Acer rubrum* (red maple), *Aluns serrulata* (smooth alder), *Quercus prinus* (chestnut oak), *Robina pseudoacacia* (black locust) and *Prunus sp*. (wild cherry) are also found on the hummock. The understory vegetation includes *Smilax sp*. (greenbriers), *Celastris orbiculatus* (Asiatic bittersweet), *Viburnum dentatum* (southern arrowwood), *Sassafras albidum* (sassafras), *Toxicodendron radicans* (poison ivy) and *Festuca trachyphylla* (hard fescue). The low marsh vegetation extends in all directions from Snake Island, mostly a broad expense of *Nuphar lutea* (spatterdock), *Zizania aquatica* (wild rice), *Sagittaria latifolia* (arrowhead), *Acoraus calamus* (sweet flag), and *Impatiens capensis* (jewelweed).

2.4.1.8 Marsh functioning

Sources of allochthonous (transported into system from outside) and autochthonous (formed within system) organic carbon include the forest through leaf fall and woody debris, emergent marsh vegetation, submerged macrophytes, and algae (Nybakken and Bertness 2005). The relative role of each of these producer groups to the overall productivity of the OPC marsh is something that needs more research. Of the three energy sources feeding into the OPC ecosystem the most variable seems to be sediments and nutrients although clearly these are coupled with the water component, which acts as primary delivery system as well as a component of organic production.

Input of inorganic nitrogen to the system is through surface water, ground water, and bacterial fixation of atmospheric nitrogen. Recent work elsewhere in the Chesapeake Bay suggests that an important source of nitrogen includes nitrate dissolved in ground water (Jordan 1991). Denitrification, the bacterial production of atmospheric nitrogen gas that occurs in the marsh also occurs in the riparian forest. The riparian forest of the Rhode River has shown to remove most of the nitrogen leaving adjacent agricultural fields whether in ground water or surface runoff (Jordan 1991). A similar process is expected to be occurring in the riparian forests of OPC.

The exports of primary production are both biotic and abiotic. The abiotic removal of organic carbon is driven by the tides and by high runoff storm events. In the absence of high energy inputs from these sources burial in the sediment would be the principal route of abiotic removal. Biotic removal from the ecosystem is accomplished by grazers and filter feeders including birds, fish, and mollusks.

The marsh and riparian forest area is used as a nursery habitat by a variety of species. *Alosa pseudoharengus* (alewives) and *Alosa aestivalis* (blueback herring) pass through the Reserve component on their way upstream to spawn in the shallower reaches of Winters Run. *A. pseudoharengus* usually arrive in early March and depart by the end of April. *A. aestivalis* spawning extends from April through mid-May (Hildebrand and Schroeder 1929, Mansueti and Hardy 1967). Also, juvenile *Brevoortia tyrannus* (menhaden) enter the downstream portions of the Reserve where they feed on large quantities of phytoplankton and particulate detritus in the water column. The open water portion of OPC is listed as a nursery area for both *Trinecthes maculatus* (hogchoaker) and *Anchoa mitchilli* (bay anchovy); (Lippson 1973). Juvenile fish will usually be present from late April to September. The timing of reproduction of these migratory fish is integrated into the prevailing pattern of weather and water movements to provide reliable access to the rich food sources of the wetland. Abundant food enables rapid growth which enhances survival when the fish move to other parts of the estuary or to the open ocean to avoid unfavorable seasonal weather changes. At least two species of filter feeding mollusks live in the tidal channels of the marsh/riparian forest, *Macoma balthica* (Baltic macoma) and *Rangia cuneata* (brackish water clam). *Rithropanopus harasii* (mud crab) can be locally abundant where mud bottoms are provided with abundant woody debris. The maintenance of the overall marsh high productivity is important to sustain the Reserve's living resources; alterations would significantly impact the system.

2.4.2 Upland Vegetation Community

2.4.2.1 Upland forest

The Leight Park property consists in a mesophytic deciduous forest community. Land elevations are higher on this side of OPC and the soil, Beltsville silt loam in moderate (5 to 10 %) slopes is moderately well drained and contains stones and clay. The forest has a well developed understory and humus layer. These forests are home to a variety of small mammals including squirrels, raccoons, and opossums and to a wide variety of song birds. This portion of the Reserve has not been surveyed, but it is an objective of future monitoring efforts.

The upland forest consists of mixed species of *Quircus spp*. (oak), *Fagus grandifolia* (beech) and *Liquidambar styraciflua* (sweetgum), *Lyrodendron tuliphira* (tulip popular) and *Carya* spp. (hickory trees). In some areas this forest is banked with fringes of emergent vegetation such as *Typha* spp. The understory includes *Ilex opaca* (American holly) and rhododendrons. In addition to being characteristic of the coastal plain forest the vegetation has been modified by previous inhabitants.

The property had been in one-family ownership for several generations with only minimal clearing for agriculture although a portion of the forest understory is given over to the cultivation of varieties of azalea and rhododendrons by the former residents. The Anita C. Leight Estuary Center is located in this portion of the Reserve component, along with public trails and a paved parking lot.

2.4.2.2 Vernal pool

The vernal pool found in OPC is unique and has not been the focus of much research. Since little is known, it has never been confirmed that it exhibits the characteristics of a true vernal pool. Vernal pools vary in size and depths, but are mostly filled with water from fall through mid-summer. The rising water table fills the pool during fall months while the snowmelt and increased rainfall feeds the pool through mid-summer (The Vernal Pool Association 2009). Furthermore, vernal pools generally support obligate species such as Fairy shrimp, Wood frogs, Spotted salamanders, Jefferson salamanders, and Blue spotted salamanders. These obligate species are dependent upon vernal pools for at least one stage of their life cycle (Upper Susquehanna Coalition 2010).

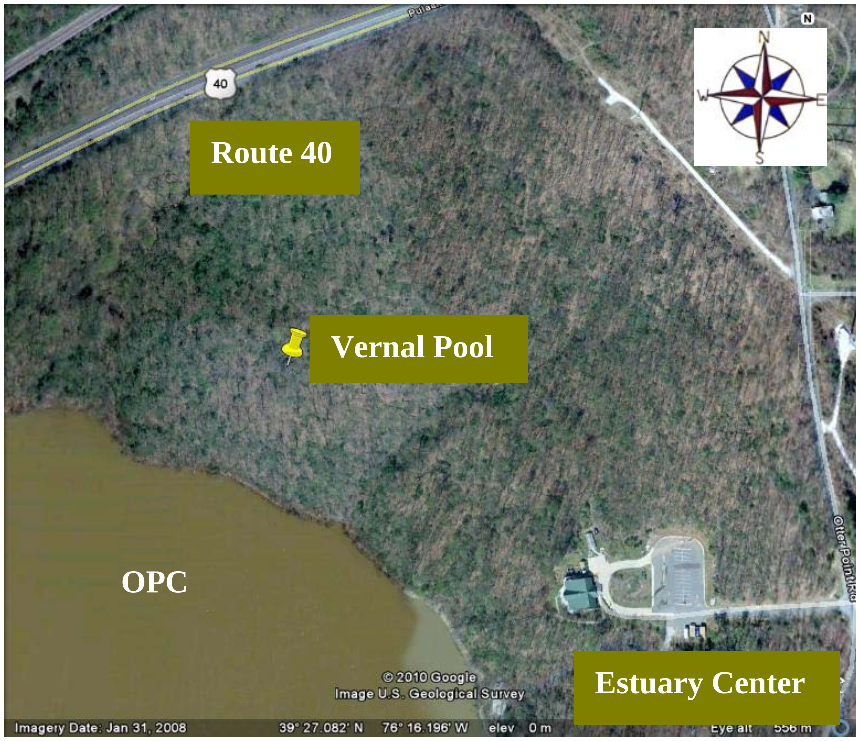


Figure 2.4.8 Location of the vernal pool at OPC.

The vernal pool at OPC is located several meters off the Discovery Trail at the Anita C. Leight Estuary Center (N 39°27.084, W 76°16.273) and is accessible by a small trail (Figure 2.4.8). The pool has been observed flooded from October through April; however, it is frozen during the winter months. Heavy rain can also intermittently flood the pond during late spring months, but the pool quickly dries. While actual depth measurements have not been recorded, the vernal pool is estimated to reach depths of approximately 38 cm (15 inches) when full. The pool is not suspected to support much life that is characteristic of vernal pools. During March and April, a few tadpoles and plentiful mosquito larvae have been observed in the vernal pool. Green frogs, a facultative species of vernal pools, have also been observed in the pool during spring months. Unfortunately, there has not been much evidence of egg masses of any species. Observations of the vernal pool at this Reserve component are qualitative; therefore, quantitative analysis of species presence/absence is necessary to confirm its classification as a "true" vernal pool.

2.4.3 Microbiological Components

Bacteria are known to be pathogenic in some cases and for decomposition and nitrogen fixation in others. Both aerobic and anaerobic bacteria are found throughout the marsh decomposing organic material accumulated in the soil from plant production. Anaerobic bacteria, found deeper in the marsh substrate, break down the organic matter into ammonium, hydrogen sulfide, methane, and other products. Hydrogen sulfide gives the marsh its characteristic rotten-egg odor. Red streaks in marsh mud also indicate the presence of oxidized iron, a common and important element in the marsh.

Fecal coliforms (fecal bacteria) are facultative-anaerobic bacteria. The presence of fecal coliform in aquatic environments may indicate that the water has been contaminated with the fecal material of man or other animals. Fecal coliform bacteria enter rivers through direct discharge of waste from agricultural and storm runoff, mammals and birds, and human sewage. In the past, beaches along the Bush River were closed to swimming due to fecal coliform bacterial contamination, linked to failing septic systems and sewage treatment plant overflows (Harford County Planning and Zoning 1984).

2.4.4 Plankton

Plankton are microscopic, free-floating organisms which are defined by the life history strategy of drifting according to the movement of the tides, winds, and currents. Plankton do not swim, per se, although some species move with the aid of cilia, flagella, or other locomotion. Some examples of plankton are diatoms, copepods, fish larvae, and jellyfish.

Plankton are classified according to their trophic level and the amount of their lifespan spent as a free-floating organism. Phytoplankton are autotrophic organisms which photosynthesize and are the main primary producers of aquatic systems. Zooplankton occupy the next trophic level, feeding on phytoplankton or bacteria (heterotrophs) or dead organisms (detritovores).

2.4.4.1 Phytoplankton

Phytoplankton are microscopic, free-floating aquatic plants and important primary producers in aquatic systems. They are the basis of most aquatic food chains, providing a major food source to many organisms which in turn are prey to organisms of higher trophic levels. In addition, and through the process of photosynthesis, phytoplankton release oxygen into the water during the daylight hours providing a benefit to the water quality in these habitats. Currently, there is no program to monitor phytoplankton at OPC.

Diatoms, dinoflagellates, cyanobacteria, green, and golden algae make up most of the phytoplankton community at OPC. Phytoplankton communities are structured by salinity, temperature, light, and nutrient availability. An excess of nutrients in the estuary during favorable growth conditions can trigger a rapid increase in phytoplankton abundance which can result in large algal blooms. Some species if found in high concentrations can become toxic causing serious health issues.

In the Bush River, occasional algal blooms often originate after large spring river flows or large rain events that bring large volumes of fresh water; this fresh water carries significant quantities of nutrients (particularly in areas with high agricultural activity or highly developed watersheds), which combined with increasing temperatures and light, produces a large increase in phytoplankton biomass or algal bloom. Phytoplankton that is not eaten by suspension feeders (such as zooplankton, oysters, and some fish) sink to the bottom where they are broken down by bacteria (Malone et al. 1986; Tuttle et al. 1987; Malone et al. 1988). This process of bacterial metabolism is aerobic and may result in severe decrease or depletion of oxygen in the water which can be detrimental to organisms such as fish and shellfish.

In some instances, fish kills in the Bush River and OPC have been attributed to low dissolved oxygen levels resulting from these episodic algal blooms. During the period 2003-2009 at least eleven harmful algal events were reported in different sections of the Bush River (Table 2.4.2). These events are often related to poor water quality conditions in the river.

Most of the algal blooms reported for the Bush River between 2003 and 2009 were associated to one species of cyanobacteria, *Microcystis aeruginosa*. Other cyanobacteria that have caused blooms in the Bush River include *Anabaena sp*., *Pseudoanabaena tenuis*, and *Karlodinium veneficum* (Cole et al. 2005; Smith et al. 2009; Harford County Planning and Zoning 1984).

Table 2.4.2 Harmful algal events reported for the Bush River for the period 2003-2009. Sources: Cole et. al. (2005) and Smith et al. (2009).

Date	Harmful Algal Event	Approximate Location
	2003	
Jul 23	*Microcystis aeruginosa*: 1.6 million cells ml^{-1} *Anabaena sp.* : 264,000 cells ml^{-1}	Bush River
Jul 28	*M. aeruginosa* : 31.3 ug toxin l^{-1}	Bush River
Aug 13	*M. aeruginosa* : 24.0 ug toxin l^{-1}	Upper Bush River
	2004	
May 11	*M. aeruginosa* : 23,250 cells ml^{-1}	Lauderick Creek
May 26	*M. aeruginosa* : 500,000 cells ml^{-1}	Bush River
May 27	*M. aeruginosa* : 1.4 million cells ml^{-1} Water described as having the appearance of green paint spilled on the surface. Health advisory published.	Bush River
Jun 01	*M. aeruginosa* : 2.97 million cells ml^{-1}	Flying Point Marina
Jun 09	*M. aeruginosa* : 2.1 million cells ml^{-1} *Anabaena sp.* : 13,992 cells ml^{-1}	Otter Point Park
Jun 14-16	*M. aeruginosa* : 12,731 cells ml^{-1} *Anabaena sp.* : 13,992 cells ml^{-1}	Lauderick Creek
	2005	
Jul 12	*Anabaena planktonica*: 63,665 cells ml^{-1} *Aphanizomenon sp.*: 47,833 cells ml^{-1} *M. aeruginosa*: 3,604 cells ml^{-1}	Otter Point Creek
	2008	
Nov 10	*Karlodinium beneficum*: 1,143 cells ml^{-1}	Otter Point Creek

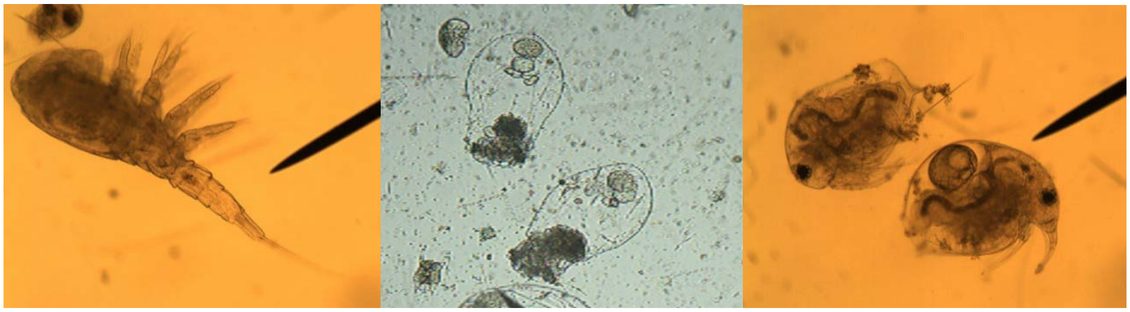
2.4.4.2 Zooplankton

Zooplankton are a diverse group of aquatic invertebrate animals ranging in size from unicellular flagellates one-hundredth of a millimeter in diameter to jellyfish one meter in diameter. Free-floating larval stages of commercially important species of oysters, clams, and crabs are also included within the zooplankton. Zooplankton consume bacteria and phytoplankton. The zooplankton community is dependent on the availability of phytoplankton and in turn is integral to the life cycle of fish, serving as a food source during fish larval stages. Excretion by zooplankton is one of the most significant recycling mechanisms that supplies phytoplankton with nitrogen and phosphorus for growth. Zooplankton are affected by algal blooms, the amount of freshwater entering the bay (especially spring discharge), toxins in the water, and other fluctuating parameters of the water.

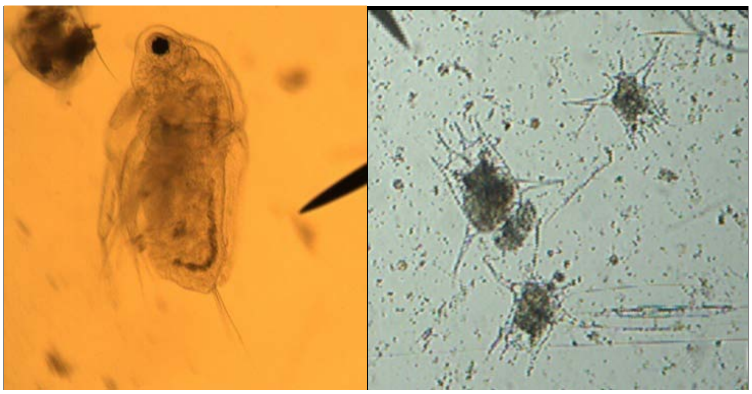
A study of the zooplankton of OPC began in 2010 by Anita C. Leight Estuary Center (ACLEC) volunteers. Zooplankton was sampled in the vicinity of the continuous monitoring station located on the pontoon boat dock near the ACLEC. Sampling took place approximately every two weeks during the summer. Samples are stored in the ACLEC laboratory. In addition, the Chesapeake Bay Program (CBP) and Maryland Department of Natural Resources (MD-DNR) have monitored the zooplankton community at specific stations within the Bay and tidal tributaries since 1984, although none of the stations sampled are on or near the Bush River and OPC. CBP Bay-wide zooplankton monitoring has been very limited recently although there is recent interest in reestablishing this program. Data and information regarding CBP and MD-DNR programs can be accessed at: http://www.chesapeakebay.net/data_plankton.aspx and http://www.dnr.state.md.us/bay/monitoring/phyto/index.html, respectively. A comprehensive list of species found within the Chesapeake Bay has been generated and updated annually with new species (Chesapeake Bay Program 2007).

The tidal freshwater zooplankton community is dominated primarily by rotifers, copepods, and cladocerans (Wilmer et. al 2000). Throughout the season, a change in the presence and proportion of species is evident in OPC, from primarily rotifers early in the summer to an increase in cladocerans and copepods at midsummer. Zooplankton density is highest in July. A high density of juvenile fish is present in samples in the month of July. In autumn, zooplankton numbers in the samples decline.

There are many different species found within the Chesapeake Bay and locally in the OPC zooplankton community. Some of the most abundant species include *Eurytemora affinis*, *Acartia tonsa*, *Cyclops spp*., *Bosmina longirostris*, and *Podon polyphemordes* (Figure 2.4.9). In addition, other abundant species found during the zooplankton survey of OPC include *Asplanchna sp.*, *Brachionus sp.*, *Scapholebris sp.*, *Diaphonosoma sp.*, and *Moina sp.* Some of the most common species at OPC are shown in Figure 2.4.9.



Copepod: *Acartia* sp. Rotifer: *Asplanchna* sp. Cladoceran: *Bosmina* sp.



Cladoceran: *Diaphanosoma* sp. Rotifer: *Brachionus* sp.

Figure 2.4.9 Examples of some of the most common zooplankton found in OPC. (Photo credit: Baker-Brosh and Mattson).

Two genera of rotifers are most prolific in early summer: *Asplanchna* and *Brachionus*. *Asplanchna* is carnivorous on other rotifer species including *Brachionus*. When *Brachionus* is living in the presence of *Asplanchna*, it grows spines on the anterior surface of the lorica (outer shell-like covering) to resist capture and consumption by *Asplanchna* (Gilbert 1966). At Otter OPC, where the two genera are found together, the spines of *Brachionus* are evident.

MD-DNR Fisheries Service regularly monitors ichthyoplankton (meroplankton) at certain subwatersheds in the Chesapeake Bay drainage basin. The Bush River was originally monitored by MD-DNR as part of this research but is now monitored by CBNEER-MD staff. Bush River data is shared with MD-DNR Fisheries Service. The larval stages of five commercially important anadromous fish species are included in this study: *Alosa sapidissima* (American shad), *Alosa mediocris* (hickory shad), *Alosa pseudoharengus* (alewife), *Alosa aestivalis* (blueback herring), *Perca flavenscens* (yellow perch), and *Morone americana* (white perch). This monitoring project, which was developed to document the spawning activity of these species in the tributaries in Maryland tidal waters, started in 1967 and was completed around 1987 (O'Dell et al. 1975). In 2005, the sampling sites for two of the watersheds (Bush River and Severn River) sampled in the old study were re-sampled to update the information on spawning habitat use. Overall results from a comparative analysis for the Bush River watershed between the 1972 and 2005 data suggests a decline in anadromous spawning and larval fish habitat use over the last thirty-three years. Historically, *M. americanus*, *P. flavenscens*, *A. pseudoharengus*, *A. aestivalis*, *A. sapidissima* and *A. mediocris* were present. Data from 2005 showed, *A. pseudoharengus*, *A. aestivalis*, *A. sapidissima* and *A. mediocris* present, but *M. americanus, P. flavenscens* absent in samples. However, historical data included collection of adults where *M. americanus, P. flavenscens* were present, and sampling of adults in 2005 was not implemented. Thus, direct comparisons between the historic data and present data are limited. *A. pseudoharengus*, *A. aestivalis*, *A. sapidissima* and *A. mediocris* were observed at seven out of twenty five stations, indicating that some streams still support spawning of these species (McGinty 2005).

Zooplankton are critical to the estuarine ecosystem. It is well known that an adequate supply of zooplankton is crucial for larval fish development (Morris and Mischke 1999). Ichthyoplankton research by MD-DNR Fisheries Service indicated a strong relationship between the presence of copepods in Chesapeake Bay watersheds and the presence of larval yellow perch. Recent examination of the gut contents of larval *P. flavenscens* showed that copepods were found in 55-100% of the fish sampled, while cladocerans were found in 2-22% of the guts (Uphoff, pers comm.). This indicates that copepods were very important for larval *P. flavenscens* success in 2010 (Uphoff, pers comm.). Recruitment for *A. sapidissima* in the Chesapeake Bay is highest during years of high spring freshwater discharge into the Bay (Hoffman et. al 2007). High freshwater discharge delivers an abundance of organic matter from the watershed. The high organic matter stimulates higher zooplankton production which serves as a plentiful food supply for larval fish (Hoffman et. al 2007). Conversely, years of low spring discharge correlate with lower levels of zooplankton production and smaller year-classes of *A. sapidissima* (Hoffman et. al 2007).

Researchers at MD-DNR Fisheries Service are interested in understanding the importance of watershed development on zooplankton dynamics and the ultimate impact of development on larval fish success rates. Qualitative observations among watersheds imply that developed watersheds where stream alteration, wetland loss, and urbanization are present, supply water to the Chesapeake Bay that is deficient in vital organic matter, possibly affecting the phytoplankton and zooplankton populations. Discharge from developed watersheds could potentially act to decrease zooplankton production or alter timing of spring blooms important for feeding success and survival of anadromous fish larvae (Uphoff, personal communication.). Conversely, water samples from undeveloped watersheds appear to contain adequate amounts of organic matter and zooplankton necessary for fish growth and survival (McGinty, personal communication). Additional research to characterize the relationship between larval yellow perch survival and watershed development among Chesapeake Bay tributaries is planned (Uphoff personal communication).

2.4.5 Benthic Macroinvertebrates

The term benthos refers to aquatic animals that live on bottom habitats including soft mud and sand, vegetated, shell, or rocky bottoms. Benthos can be considered as the “middlemen” in the aquatic food chain and play a critical role in the flow of nutrients and energy. They feed on algae and bacteria and are an important part of the food chain, especially to fish. Benthic macroinvertebrates include: phylum Annelida (worms and leeches), phylum Mollusca (clams and snails), and phylum Arthropoda (crayfish) and immature forms of aquatic insects (stoneflies and mayflies).

Benthos are considered good indicators of the health of aquatic habitats for various reasons:

- Live in the water for most of their life.
- Have limited mobility, not able to escape the effects of sediment and pollutants that diminish water quality.
- Represent an extremely diverse group of aquatic animals who differ in tolerance to amount and types of pollution.
- Remain in areas suitable for their survival.
- Easy to collect.
- Easy to identify in a laboratory.
- Often live longer than a year.

Based on adult size benthic invertebrates are classified in three groups: meiobenthos which includes the smallest organisms, macrobenthos, and megabenthos (individuals several centimeters in size). For the purpose of this site profile, we are focusing on macrobenthos; these include organisms that are retained in a 500 um mesh screen, but cannot be identified without magnification. In estuaries, examples of this group include annelid worms, bivalves, gastropods, crustaceans, tunicates, and insects' larvae.

The sampling of benthos is based on the type of aquatic habitat being studied, and can be conducted to monitor water quality over a broad area or at point source discharges. Ecologists use various characteristics when using benthos as indicators of water quality. One characteristic is pollution tolerance. Certain benthic organisms are sensitive to pollutants. For example, mayflies are intolerant of pollution, so the collection of large numbers is an indication of good water quality. Another characteristic is taxa richness (or number of species); the greater the taxa richness the greater the water quality. Another characteristic is functional groups. The absence or presence of certain feeding groups can indicate a disturbance in the food supply and therefore the presence of toxic chemicals or other contaminants.

The benthic macroinvertebrate community of OPC has not been the focus of much research; the only existing study was conducted by MD-DNR, Maryland Biological Stream Survey (MBSS). The main objectives of this study were to (1) characterize the ecological condition of the major tributary sub-watersheds that feed into OPC; (2) identify likely sources and locations of stressors to streams in the area; and (3) examine the efficacy of restoration work conducted in non-tidal portions of the watershed. Complete methodologies and results for this study can be found in Stranko et al. (2007).

MBSS sampled 42 non-tidal and 2 tidal sites in and around the OPC component in 2000-2004, and in 2006. Only results from the closest more direct tributaries to OPC, Lower Winters Run (below Atkisson Reservoir) and HaHa Branch, will be discussed in this section.

Lower Winters Run

Stream ecological conditions at non-tidal sites, as measured by benthic macroinvertebrate and fish indices of biotic integrity (IBI) scores, ranged from 1.0 (poor) to 4.67 (good). Streams with high ecological conditions included the main-stem of Winters Run and OPC, Mountain Branch, and one unnamed tributary draining from the western portion of the town of Abingdon. Although these areas remain in good condition, poor ecological conditions were observed in three unnamed tributaries and in portions of the Winters Run main-stem. At six of the eleven sites sampled in Lower Winters Run, benthic IBI scores indicated poor conditions (Figure 2.4.10). Stream fish communities at seven of the eleven sites were in good condition (Stranko et al. 2007).

The ecological health of this watershed seems most threatened by urban development and the associated increases in impervious land cover occurring in and around the town of Bel Air. The percentage of impervious land cover upstream of all sites sampled in the Lower Winters Run exceeded two percent, which is a level that has been shown to cause the loss of species and declines in biological integrity of streams. Upstream impervious surface at three sites sampled in this watershed was greater than 10% which is a level consistently associated with poor biological integrity and a complete loss of sensitive species. Continued urbanization threatens areas of high biological integrity still remaining in the non-tidal mainstem and in tributaries to Winters Run and OPC. Tidal portions of this system would probably also degrade as impervious land cover increases upstream (Stranko et al. 2007).

Haha Branch:

The ecological condition of this stream, as measured by the fish IBI score, was fair. While the condition of the benthic macroinvertebrate habitat was also fair, the benthic macroinvertebrate community was in poor condition (Figure 2.4.10). Even though only one site was sampled in Haha Branch in 2006, it seems that impervious land cover is a major stressor in this tributary. Upstream impervious land cover measured at this site was 8.5 %, a level associated with low biological integrity (Stranko et al. 2007).

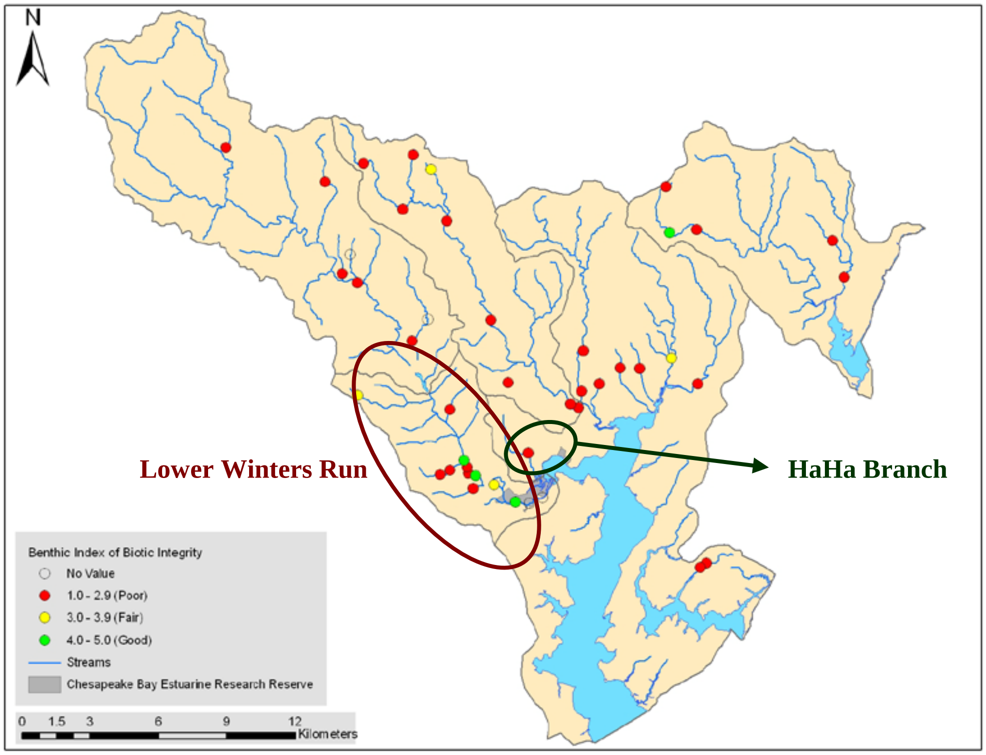


Figure 2.4.10 Benthic Index of Biotic Integrity scores for sites sampled in tributaries to the OPC Reserve component. Highlighted are the sites for the Lower Winters Run and HaHa Branch. Source: Stranko et al. (2007).

A list of the species collected from all sampling sites during the duration of the MBSS study is provided in Table 2.4.3. A total of 75 species were collected; from these 19 species (25%) were found only in the tidal sites, and 13 species (17%) in both non-tidal and tidal sites. From the species collected in the two tidal sites *Polypedilum sp*. (midges, moucherons), *Gammarus sp*. (amphipods), *Limnodrilus sp*. (oligochaetes), and *Orthocladius sp*. (midges, moucherons) were the most abundant (Stranko et al. 2007).

Table 2.4.3 Partial species list of benthic macroinvertebrate fauna collected in non-tidal and tidal sites of the lower Winters Run, a tributary to OPC. Source: Information source: Stranko et al. (2007).

Phylum	Class	Order	Family	Species	Common Names
Annelida	Clitellata	Haplotaxida	Naididae	**Naididae**	Earthworms
			Tubificidae	***Limnodrilus***	Earthworms
				Spirosperma	Earthworms
	Clitellata	Lumbriculida	Lumbriculidae	***Lumbriculidae***	Earthworms
		Rhynchobdellida	Piscicolidae	**Piscicolidae**	Leeches
Arthropoda	Insecta	Coleoptera	Elmidae	***Ancyronyx sp.***	Riffle beetles
				Dubiraphia	Riffle beetles
				Macronychus	Riffle beetles
				Microcylloepus	Riffle beetles
				Oulimnius	Riffle beetles

Phylum	Class	Order	Family	Species	Common Names
			Haliplidae	***Peltodytes***	Crawling water beetles
			Hydrophilidae	***Berosus***	Water scavenger beetle
			Psephenidae	***Psephenus***	Water-penny beetles
		Diptera	Ceratopogonidae	**Ceratopogonidae**	Midges
			Chironomidae	***Cardiocladius***	Midges
				Chironomus	Midges
				Cricotopus	Midges
				Cryptochironomus	Midges
				Cryptotendipes	Midges
				Diamesa	Midges
				Dicrotendipes	Midges
				Endochironomus	Midges
				Eukiefferiella	Midges
				Hydrobaenus	Midges
				Microtendipes	Midges
				Nanocladius	Midges
				Orthocladius	Midges
				Parachironomus	Midges
				Parametriocnemus	Midges
				Paraphaenocladius	Midges
				Paratendipes	Midges
				Phaenopsectra	Midges
				Polypedilum	Midges
				Rheocricotopus	Midges
				Rheotanytarsus	Midges
				Stempellinella	Midges
				Stictochironomus	Midges
				Tanytarsini	Midges
				Tanytarsus	Midges
				Thienemannimyia group	Midges
				Trissopelopia	Midges
				Tribelos	Midges
				Tvetenia	Midges
			Empididae	***Hemerodromia***	Balloon flies, dance flies
			Simuliidae	***Prosimulium***	Black flies, buffalo gnats
				Simulium	Black flies, Buffalo gnats
			Tipulidae	***Antocha sp.***	Crane flies, tipules
				Tipula	Crane flies, Tipules
		Ephemeroptera	Ephemerellidae	***Ephemerella***	Spiny crawler mayflies
				Eurylophella	Spiny crawler mayflies
				Serratella	Mayflies
			Heptageniidae	***Stenonema***	Mayflies
			Isonychiidae	***Isonychia***	Mayflies
		Hemiptera	Belostomatidae	***Belostoma sp.***	Electric light bugs, giant water bugs
		Lepidoptera		***Lepidoptera***	Butterflies
			Pyralidae	***Pyralidae***	Grass moths, Snout moths
		Megaloptera	Corydalidae	***Nigronia***	Dobsonflies, fishflies, hellgrammites

Phylum	Class	Order	Family	Species	Common Names
		Odonata	Calopterygidae	***Calopteryx***	Broad –winged damselflies
			Coenagrionidae	**Coenagrionidae**	Narrow-winged damselflies, pond damsels
			Corduliidae	***Macromia***	Emeralds, green-eyed skimmers
			Gomphidae	***Hagenius***	Clubtails
		Plecoptera	Perlodidae	***Perlodidae***	Perlodid stoneflies
		Trichoptera	Brachycentridae	***Micrasema***	Caddisflies
			Hydropsychidae	***Cheumatopsyche***	Net-spinning caddisflies
				Hydropsyche	Net-spinning caddisflies
			Philopotamidae	***Chimarra***	Finger-net caddisflies
	Malacostraca	Amphipoda	Crangonyctidae	***Crangonyx***	Amphipods
			Gammaridae	***Gammarus***	Amphipods
Mollusca	Bivalvia	Veneroida	Corbiculidae	***Corbicula***	Asian clam
			Sphaeriidae	**Sphaeriidae**	Pea clams, fingernail clams
			Pisidiidae	***Sphaerium***	Pea clams
	Gastropoda	Basommatophora	Physidae	***Physella***	Physa
Nematomorpha	Gordioida	Gordea	Gordiidae	**Gordiidae**	Horsehair worms
Nemertea	Enopla	Hoplonemertea	Tetrastemmatidae	***Prostoma***	Ribbon worms
Platyhelminthes	Turbellaria	Tricladida	Planariidae	***Dugesia***	Triclads

Color coding: **Black (found in non-tidal sites)**; **Red (found in tidal sites)**; **Blue (found in both non-tidal and tidal sites)**.

2.4.6 Fish, Reptiles, and Amphibians

The information provided in this section, unless otherwise indicated, has been summarized from various information sources, which are listed in the reference section of this site profile.

The abundance and diversity of fish, amphibians, and reptiles within an estuary can help assess its overall ecosystem health. It has been proposed that amphibians are good indicator species due to their sensitivity to changes in their environment. Even though OPC is virtually land-locked by development, over 70 species of fish, amphibians, and reptiles still thrive here in this small suburban sanctuary.

Many of the animals in this group require one or both an aquatic and terrestrial habitat for breeding and adulthood. So it is important that OPC has a variety of habitats to offer these species. OPC consists of four main habitat types: upland forest, forested wetlands, tidal marsh, and open water. The upland forested area accounts for most of land in the Leight Park area. These upland areas are comprised of deciduous trees and shrubs, such as red maple, river birch, mountain laurel, sassafras, and high-bush blueberry. A vernal pool is also located in this habitat and supports a few species of frogs during the spring and early summer (Figure 2.4.11). The area is not flooded by a creek nearby since it is generally between 20 and 40 m above the water level. Many species of terrestrial turtles (box turtles) and reptiles inhabit this area.

Photo credits: K.Keller

Figure 2.4.11 Vernal Pool and tidal freshwater marsh at OPC.

The forested wetlands are a much smaller part of Leight Park; however they cover almost the entirety of the Bosely Conservancy. Species found there include deciduous trees, shrubs, marsh plants, and several invasive species. These areas are characterized by an over-story of trees, an understory of young trees or shrubs, and an herbaceous layer. The Bosely Conservancy is generally only up to 3 m above the water level. This area contains many species of amphibians and reptiles.

The tidal freshwater marsh is a large part of the western area of the OPC component between the Bosely Conservancy and the open water. Its mostly soft clay and silt bottom supports many species of both submerged and emergent vegetation. This marsh receives the tidal signal from the Chesapeake Bay and is inundated twice a day following the tidal cycle. These areas are known for their high species diversity and are home to aquatic turtles and some snakes.

The open water area of the OPC component is over 105.2 hectare (260 acres) and supports many species of submerged aquatic vegetation. It looks more like a small lake than a creek and its depth is generally less than 2 m (6.6 ft.). Surrounded by marsh vegetation, this area provides a safe habitat for larval and adult fish and aquatic turtles.

2.4.6.1 Fish

Since sampling by Reserve staff began in 2001 over 40 different species of fish have been identified from OPC and the Bush River. Some of the more abundant fish species include: *Fundulus diaphanous* (banded killifish), *Alosa aestivalis* (blueback herring), *Lepomis macrochirus* (bluegill), *Dorosoma cepedianum* (gizzard shad), *Notemigonius crysoleucas* (golden shiner), *Menidia beryllina* (inland silverside), *Lepomis gibbosus* (pumpkinseed), *Notropis hudsonius* (spottail shiner), *Etheostoma olmstedi* (tessellated darter), *Morone americana* (white perch), and *Perca flavescens* (yellow perch). A more comprehensive list of fish species reported from the Anita C. Leight Estuary Center can be found in Appendix I.

MD-DNR Fisheries Service collaborates with the Reserve on volunteer staffed fish monitoring programs. Through these monitoring efforts population dynamics are evaluated. Also, several species have shown decline from the programs inception. It is suspected that increased urbanization within the watershed may be negatively impacting important spawning areas. Efforts to examine these issues include

- Yellow Perch Larval Monitoring Program
- Larval Fish Survey
- Juvenile Fish Sampling

Yellow Perch Larval Monitoring Program

P. flavescens are an important recreational and commercial fishery in OPC and the Bush River. Their populations however, have been declining since the early 1980s. Research conducted at the reserve from 2005-2009 shows a decrease in *P. flavescens* encountered during the sampling (Figure 2.4.12). Possible reasons for decline include decreased water quality resulting from an increase in urban and industrial development. In 1989, the situation was critical enough that nine watersheds within the Chesapeake Bay were closed to commercial *P. flavescens* fishing and six closed to recreational fishing. The commercial and recreational interest in yellow perch dictates a research focus. In conjunction with the MD-DNR Fisheries Service, a *P. flavescens* larval study is ongoing in the Reserve. The study monitors the presence and temporal distribution of larval *P. flavescens* in the Bush River.

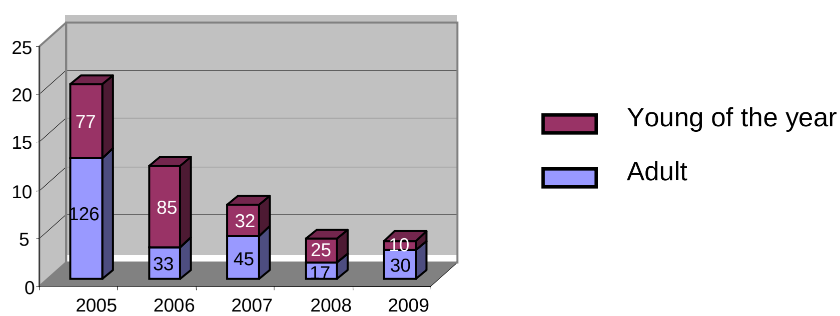


Figure 2.4.12 Juvenile fish sampling between 2005 and 2009 shows a decline in yellow perch caught in trawl and seine nets.

Between late February and early March yellow perch spawn in OPC and the Bush River. During this period both historic and new sites are searched for yellow perch egg masses (Figure 2.4.13). In late March, ten sites on the Bush River are sampled for larval yellow perch using plankton net. The net is towed for two minutes and the sample is placed into a tray for larvae identification. Water quality data is recorded at each location. These data help determine the residence time of yellow perch larvae in the Bush River. The data indicated that yellow perch hatch out during the last week of March and by the first two weeks of April are absent from the sampling area. There appears to be a correlation between their departure and water temperature.

Photo credits: Coastal Conservation Association.

Figure 2.4.13 Yellow perch and yellow perch egg case.

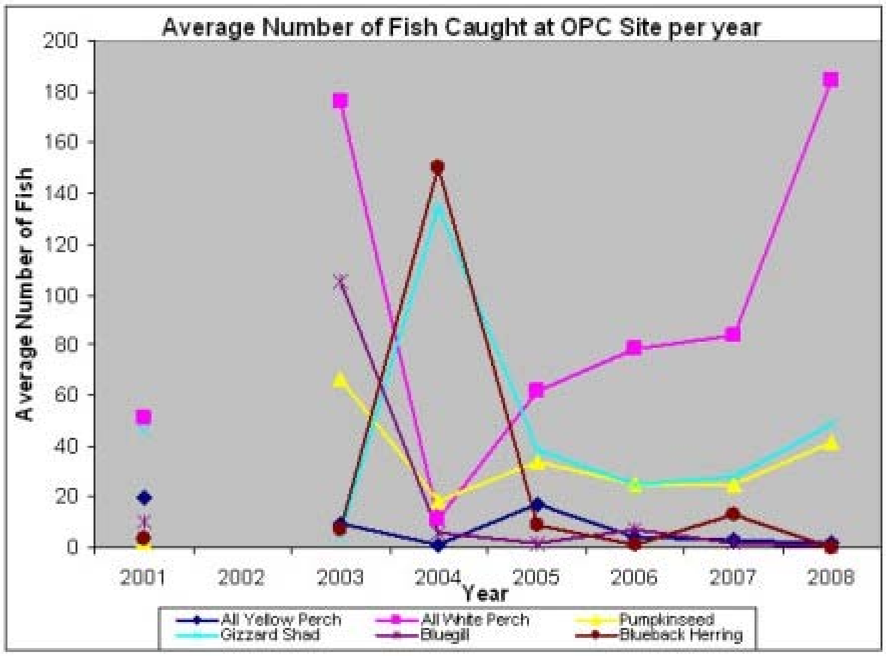
Juvenile Fish Sampling

The juvenile fish sampling survey assesses the habitat quality and overall health of the fish community in OPC. This is done by collecting baseline data to monitor tidal fish species. These data are used to track trends in the fish populations, species composition, age and abundance of commercially important species. Staff and volunteers sample four tidal sites along the Bush River during each sampling event. A 30.5 m (100 ft.) beach seine and the quarter sweep method are used to collect fish. Once the seine is landed, fish are counted, sorted and certain species are measured (Figure 2.4.14). Three of the sites are simultaneously sampled by boat using a 4.9 m (16 ft.) trawl. The trawl is deployed for six minutes and towed at a speed of two knots. Once the fish are landed they are counted, sorted and certain species are measured.

Photo credit: Anita C. Leight Estuary Center.

Figure 2.4.14 Fish seining part of the juvenile fish sampling survey at Otter Point Creek.

Preliminary results from the fish seining surveys shows high inter-annual variability in the abundance of several of the species sampled (Figure 2.4.15). Through the years, white perch numbers are consistently higher than other species, which suggest a healthy population in OPC.



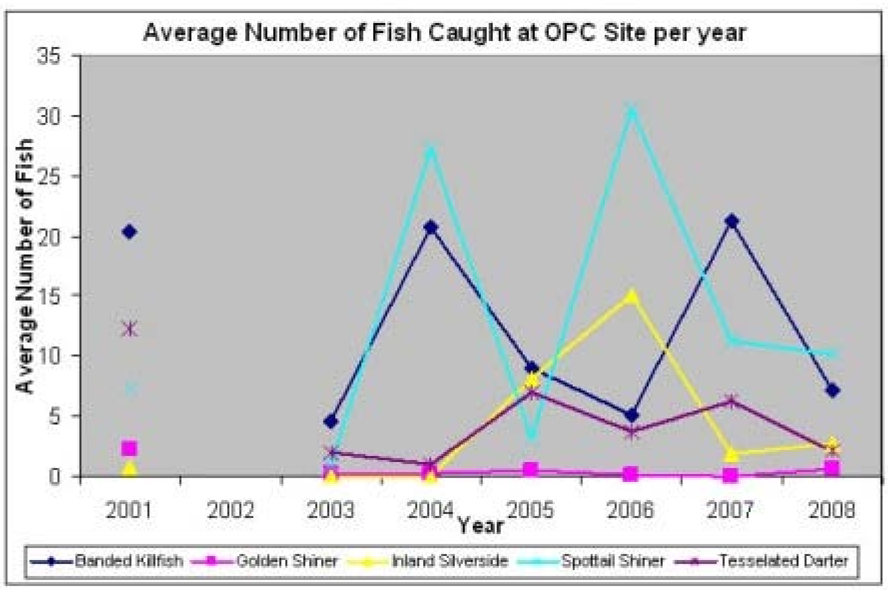


Figure 2.4.15 Average number of fish caught per species at the Otter Point Creek fish seining sampling site.

Larval Fish Survey
Anadromous fish populations in Chesapeake Bay, Maryland have been declining over the last several decades. Over this same time period significant urbanization in the Baltimore area has occurred, with unknown impacts to the spawning habitats of anadromous fish species. A survey that spanned twenty years was conducted, beginning in 1967, to document the spawning activity of *A. sapidissima*, *A. mediocris*, *A. pseudoharengus*, *A. aestivalis*, *P. flavescens*, and *M. americana*. Over this time period all suspected spawning tributaries in Maryland tidal waters were surveyed. These data are still being cited in permit review and land use decision processes, despite skepticism over the validity of using thirty-year old records. In an attempt to update these records, the MD-DNR Fisheries Service strived to repeat this survey using volunteers. A three-year larval fish project was initiated to assess the percent change in the presence of migratory fish eggs and larvae. Fifteen sites on tributaries of the Bush River were used to collect water quality data and a five-minute icthyoplankton sample to be sorted and identified for larval fish and eggs. Presence of migratory fish eggs and larvae were recorded and evaluated to determine the range of spawning and larval habitat in the Bush River. The results of the survey showed that most migratory species are not utilizing spawning areas upstream in the OPC and Bush River systems.

Commercial and recreational fishing
The Bush River watershed supports a network of streams and a dynamic freshwater tidal marsh ecosystem which provides important spawning grounds for a variety of anadromous and estuarine fish species. As such, the Bush River sustains an important local commercial and recreational fishing industry. Fish harvest in the Chesapeake Bay is regulated by MD-DNR. The MD-DNR records of commercial fish catch for the Bush River date back to 1972. These records detail the type of fish harvested, landings numbers, and the general fishing location. These records have been used by MD-DNR to keep track of the commercial landings within the Chesapeake Bay, to monitor and enforce compliance with state management regulations, and to develop single stock species assessments. In a general effort to characterize commercial fish harvesting within the Bush River, MD-DNR records from 1972-2004 were analyzed to examine temporal trends of total fish catch, changes in main targeted species, and species relative importance of total harvest (Figure 2.4.16, Table 2.4.4).

Total fish catch in the Bush River during the period 1972-2004 shows a slight increase, particularly during the last years (1996-2004). Catch, however, is not even throughout with some years being more productive than others. The total yearly fish catch varied greatly and ranges from 13,545 to 117,491 kilograms (29,800 to 258,479 pounds). Such fluctuations can result from variable yearly catch per unit effort (CPUE), changes in demand, and/or reduced fish populations. Total catch reported for the period 1972-2004 included, catfish (Ictaluridae), *M. americana* and *P. flavescens* which contributed 64% of the total. The other two species that rounded out the top five were *Morone saxatilis* (striped bass) and *D. cepedianum* (Figure 2.4.16).

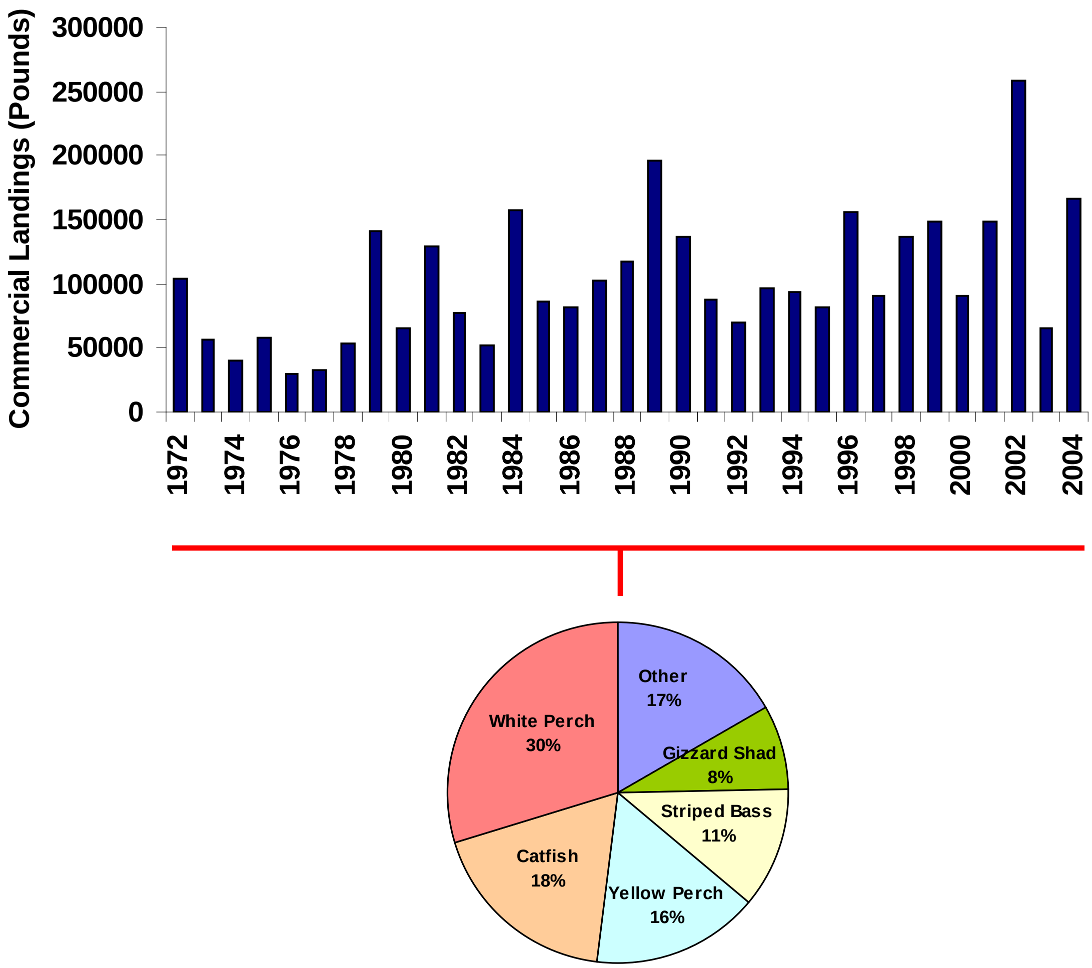
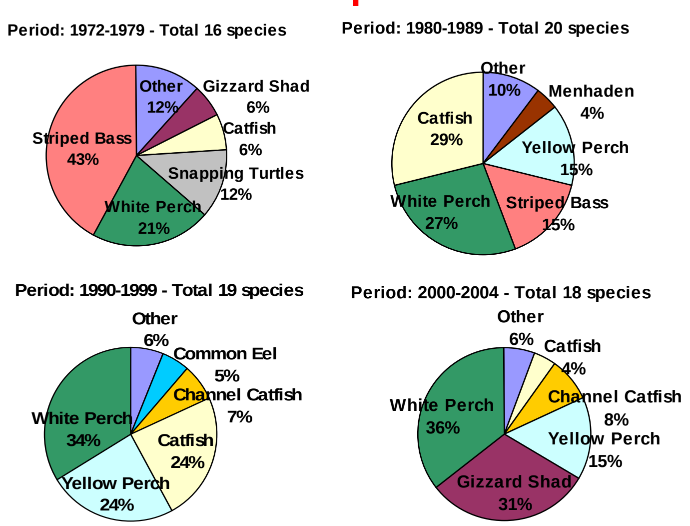


Figure 2.4.16 The bar graph indicates yearly fish catch in the Bush River from 1972 to 2004. The pie chart represents total catch distribution by species during the same time period. A total of twenty-seven species were reported during the study period, but only the top five species are represented in the pie chart; the rest of the species are grouped under the “other” category. Data presented in this figure was not corrected for gear type and catch per unit effort (CPUE). Data source: MD-DNR Fisheries Service Department. Data analysis: P. Breintenbach, CBNERR-MD research intern 2008-2009.

Within the Bush River a total of 26 different species have been targeted for fishing (Table 2.4.4). The top five targeted species yielding most of the catch has changed through time depending on market demand, fishing regulations, population, natural productivity and/or other undetermined reasons. *M. saxatilis* (striped bass), for example, provided 43% and 15% of the total catch for the periods 1972-1979 and 1980-1989, respectively, but was not among the top five targeted species during the rest of the time period analyzed (1990-2004). In contrast, *D. cepedianum* (gizzard shad) has gained importance as a catch species during the most recent years (2000-2004), while *M. americana* (white perch) and *P. flavescens* (yellow perch) have been important throughout most of the surveyed time period (Table 2.4.4.).

Table 2.4.4 Fish species reported as catch within the Bush River; species are listed for four different time periods. The multiple pie charts indicate total catch distribution by species during each of four time periods. Only the top five species are represented in each of the pie charts; the rest of the species are grouped under the "other" category. Data presented in this table was not corrected for gear type and catch per unit effort (CPUE). Data source: MD-DNR Fisheries Service Department. Data analysis: P. Breintenbach, CBNERR-MD research intern 2008-2009.

Scientific Name	**Common Name**	**1972 - 1979**	**1980 - 1989**	**1990 - 1999**	**2000 - 2004**
Anguilla rostrata	American eel	X	X	X	X
Pomatomus saltatrix	Bluefish	X	X		X
Ameiurus sp.	Bullhead Catfish			X	X
Peprilus sp.	Butterfish			X	
Cyprinus carpio	Carp	X	X	X	X
Ictalurus spp.	Catfish	X	X	X	X
Pomoxis spp.	Crappie	X	X	X	X
Species not specified	Finfish	X	X		
Dorosoma cepedianum	Gizzard shad	X	X	X	X
Cynoscion regalis	Gray sea trout		X		X
Alosa mediocris	Hickory shad	X	X		
Brevoortia tyrannus	Menhaden	X	X	X	X
Mugil spp.	Mullet – black or silver		X	X	
Alosa pseudoharengus	River herring	X	X	X	X
Species not specified	Shad	X	X	X	
Morone saxatilis	Striped bass	X	X	X	X
Species not specified	Suckers: Castostomidae	X	X	X	X
Paralichthys dentatus	Summer flounder		X		
Species not specified	Unknown			X	
Ameiurus catus.	White catfish			X	X
Morone americana	White perch	X	X	X	X
Merlangius merlangus	Whiting			X	X
Pseudopleuronectes americanus	Winter flounder		X		
Perca flavescens	Yellow perch	X	X	X	X
Total Species	**25***	**15** *	**19** *	**18**	**17** *



* Snapping turtles reported as catch

2.4.6.2 Reptiles and amphibians

Reptiles and amphibians are good indicators of ecosystem health due to their close association with aquatic habitats and their sensitivity to different stressors. Evidence links global reptile and amphibian population declines to habitat destruction, and possibly to degraded water quality, deforestation, highway construction, and urban development. The role that these factors and other potential stressors (contaminants, introduced species, climate change, ultraviolet radiation, disease, and atmospheric deposition) play in the loss of these animals has not been determined. To help answer these questions, reptile and amphibian populations are monitored at OPC. This data will provide information regarding species diversity, distribution, habitat preferences, relative abundance, and overall health of reptiles and amphibians within the OPC Reserve. Volunteers assist with monitoring through the following studies: Visual Encounter Survey, Coverboard Study, and the Box Turtle Study. Additionally, high school and college interns conduct projects designed to answer specific questions about reptile and amphibian populations within the OPC component.

Visual Encounter and Coverboard Studies

Reptile and amphibian data is currently collected using Visual Encounter and Coverboard methodologies. These are long-term monitoring projects conducted in the upland forested area of the OPC component within the Leigh Park. Data collected includes: species diversity and abundance to determine changes in populations over time. Fourteen 25 m by 25 m (82 ft. by 82 ft.) predetermined sites (not including aquatic habitats) were selected at least 75 m (246 ft.) from the forest edge to eliminate edge effects. Based on vegetation cover, three coverboards are placed in each of the sites. Volunteers search the surface, vegetation, under rocks and logs, and in crevices while minimizing their disturbance before searching the coverboards. Any species found under the coverboards are listed on the coverboard data sheets. All other species found in the site are listed on the visual encounter data sheets. It has been noted that no site seems to have particularly fewer encounters than any other. A list of species found within Leight Park is included in Table 2.4.5.

Table 2.4.5 Reptile and amphibian species found at Leight Park, OPC.

Species Found	Number of Species Found to Date	
	Visual Encounter Study	Coverboard Study
American Toad	8	2
Black Rat Snake	6	0
Eastern Box Turtle	7	0
Eastern Garter Snake	6	1
Eastern Two-lined Salamander	0	1
Eastern Worm Snake	6	0
Green Frog	4	0
Grey Treefrog	1	0
Northern Black Racer	2	0
Northern Ringneck Snake	7	3
Northern Water Snake	3	0
Redback Salamander	26	8
Pickerel Frog	2	0

Turtle Telemetry

Terrapene carolina carolina (Eastern box turtle) were once a frequent and beloved reptile found in Maryland's woods. In recent years, however, *T. carolina carolina* populations have started to diminish, resulting in far fewer encounters. The primary causes for their decline are urbanization, the construction of roads, and collection as pets. To gain a better understanding of population dynamics, habitat requirements, and home ranges, volunteers and interns of the Anita C. Leight Estuary Center monitor *T. carolina carolina* populations through radio telemetry.

Once a new turtle is found, the GPS position as well as data regarding habitat, weather, and turtle behavior are recorded. Small radio transmitters are then attached to the turtle carapaces (the top portion of the shell, Figure 2.4.17). Each transmitter operates on a different frequency that is picked-up by a receiver allowing volunteers and interns to track the turtles on a weekly basis. Currently, twelve turtles are tracked through radio telemetry at least twice a week. The GPS data collected is used to map the home ranges of each turtle. Most importantly, the data yields turtle habitat preference as well as the amount of space required by each turtle.

Photo credits: Anita C. Leight Estuary Center

Figure 2.4.17 Eastern Box turtle with radio transmitter (left) and with thread spool (right); OPC box turtle monitoring program.

In addition to tracking the twelve turtles through radio telemetry, all other turtles found are monitored by using a notch code system. Upon capture, the age, sex, size, weight, GPS location, and anything unusual is recorded. To date, 81 turtles have been found and notched; many have been recaptured at least once. Data collected from the notch code system allow volunteers and interns to monitor the turtle population trends (turtle health, size, age, sex ratio, etc.) of the OPC Reserve.

Turtle Thread Survey
Turtle thread surveys provide another useful methodology for monitoring *T. carolina carolina* at the OPC Reserve. Upon capture, duct tape is used to attach spools of dental floss (thread) to the turtle carapace (2.4.17). The turtle is released and as the turtle walks, the thread unwinds leaving the path the turtle travelled. The goals of the *T. carolina carolina* thread surveys are to determine the uses of Leight Park as female nesting locations, turtle movement ratios, and habitat preference.

To date, there has been no evidence of females utilizing Leight Park for nesting purposes because no turtle nests have been found. While females may not be using the Reserve as nesting sites, the thread surveys have provided valuable information regarding turtle movement ratios. At the end of each survey, the total thread released is measured and is compared to a straight line that is measured from where the turtle started to where it stopped. This correlates actual turtle distance to distance moved in a straight line. In addition to turtle movement, a large grid consisting of 219 plots (3m x 3m each) was constructed to provide percent cover data on all of the major shrub species in the thread survey study area. Therefore, when a thread survey is conducted in the grid, all the plots through which the turtle passed are recorded. This data is being used to explore correlations between shrub species and turtle movement to help estimate turtle habitat preference.

2.4.7 Birds and Mammals

2.4.7.1 Birds

Long-time residents and community members of the area reported a decline in the population of wintering waterfowl. Arthur Pierce Middleton in Tobacco Coast (1984) described an upper Chesapeake Bay flock of waterfowl “as one mile wide and three miles long”. Populations of this size were apparently common in the upper Chesapeake Bay, but as a result of declining submerged aquatic vegetation habitat and overhunting, waterfowl populations have since then sharply decreased.

The open water habitat at OPC Reserve is considered to be prime *Aix sponsa* (wood duck) nesting habitat. Its preservation is necessary to prevent further declines in the population of *A. sponsa* in the Chesapeake region (Haramis 1991). This habitat is becoming less common in the region due primarily to changes in land use associated with urbanization.

The riparian woodland is managed for optimum production by the provision of shelter, food sources, and the control of human intrusion. The Izaak Walton League (The League) manages the Bosley Conservancy portion of the OPC Reserve for maximum production of two waterfowl species of interest to hunters: *A. sponsa* and *A. platyrhynchos* (mallard). Although *A. platyrhynchos* has a rather broad habitat preference, the habitat requirements for *A. sponsa* are coupled to interior bottomland hardwood forests. *A. sponsa* requires sheltered backwaters not far from forest cover or nearshore emergent vegetation in order to successfully reproduce. They prefer the close overhead woody cover of the well developed forest understory or flooded timber with numerous snags and windfalls (Haramis 1991). "Obligate cavity nesting is the wood duck's strongest ecological tie with old growth forest, whereas much of the food of the wood duck is intricately tied to the seasonal water dynamics of flood plain forests and associated wetland. Availability of early spring aquatic invertebrates is especially critical for the nutrition of laying females. Throughout most of their range wood ducks have ecological ties to beaver that create forested wetlands and to the pileated woodpecker, whose nest sites and numerous foraging excavations help create nest cavities for wood ducks" (Haramis in Funderburke et al. 1991).

The Bosley Conservancy contains a significant portion of habitat that meets the criteria for successful *A. sponsa* nesting. In an effort to promote *A. sponsa* populations within this area, The League supplements natural tree cavities with an array of *A. sponsa* nesting boxes formed of molded plastic, sheet metal, or lumber. These are distributed in shallow flooded portions of the forest where there are not sufficient woodpecker holes in old trees, but provide sufficient high quality food for successful egg laying and brood rearing. The League maintains records of nest box usage and often reports good yearly production of *A. sponsa* from the riparian forest community. The areas where active *A. sponsa* nesting is occurring are posted and patrolled to reduce the impact of human activity during the reproductive season.

During the non-breeding period *A. sponsa* feeds on submerged aquatic vegetation (SAV), water lilies, duckweed, and seeds from sedges and grasses. In the fall, the OPC marsh produces arrow-arum fruits, wild rice, acorns, black cherries, and the seeds of sweet gum, beech and hickory, all of which *A. sponsa* prefers. During the breeding season, the female shifts to a diet of aquatic insects, snails, small crustaceans, fish and amphibians (Haramis, 1991). These food organisms are abundant in the seasonal pools of water which accumulate just upstream of log jams and south of Route 40. *A. sponsa* ducklings also require a high percentage of animal food during their first few weeks of life to meet the protein demands of rapid growth. A survey of the species presence and abundance of the invertebrate and amphibian fauna in the flooded forested region is needed and should be addressed in future Reserve research efforts.

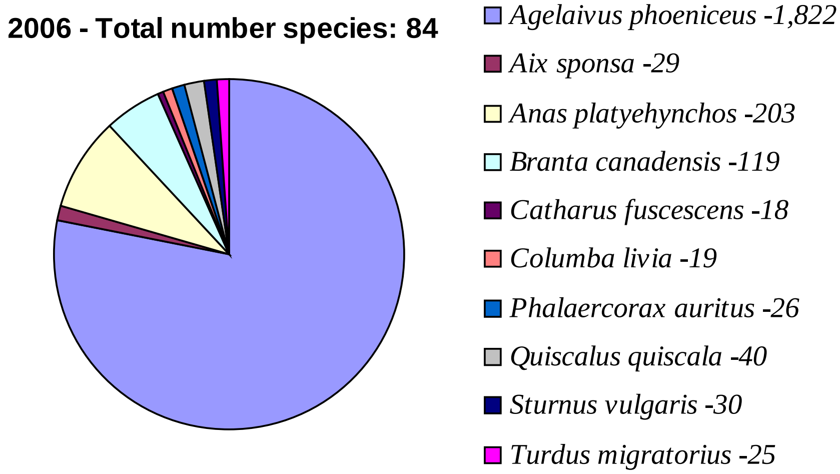
The Living Resources Subcommittee of the Chesapeake Bay Program strongly recommends the protection of hardwood floodplain forests upstream from large marshes in order to protect the populations of *A. sponsa*. The flooded forest and shrub swamp of the Bosley Conservancy provide the flooded dead timber interspersed with button bush shrub and other woody cover ideal for *A. sponsa* production. As more shorelines of the Chesapeake Bay and tributaries is developed, the ideal nesting habitat of the Bosley Conservancy will become increasingly crucial to the maintenance of *A. sponsa* populations in this region.

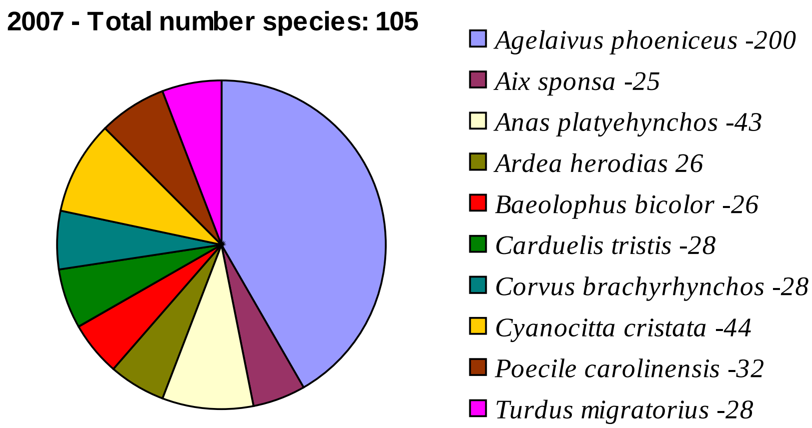
A. platyrhynchos is the most common duck in much of the Chesapeake - they adapt well to human disturbance and have a wide range of food preferences. In a similar effort to that for *A. sponsa*, the League seeks to maximize the production of *A. platyrhynchos* from the marsh through the construction of nest shelters which provide food, shade, and protection from non-human predators.

These nest shelters are constructed from heavy wire mesh rolled into a tube and anchored with the cylindrical axis horizontal. During the nesting season the cylinders are woven with hay providing a thick thatched wall on which the hen can graze without having to leave the eggs she is incubating. Crows, raccoons, and snakes are predators on the eggs of the mallard. Predation is reduced by elevating the nesting tube from the surface of the marsh.

Other waterfowl species found utilizing the OPC marsh area include *Butorides striatus* (green-backed herons), *Ardea herodias* (great blue herons), and *Egretta thula* (snowy egrets). These feed along the stream channels and roost in the trees. Downed tree trunks in the stream channel provide feeding sites for these wading birds.

In addition to waterfowl, many other species of birds utilize the different habitats found in the OPC Reserve. Since 2006, a Bioblitz has been organized at this Reserve component to increase knowledge and awareness on the biodiversity of this area. A Bioblitz consists in a special type of field study, where a group of scientists and volunteers conduct an intensive 24-hour biological inventory, to try to identify and record different species of living organisms in a given area. As part of the annual Bioblitz organized at the OPC component, bird observations were conducted throughout the area including forest and marsh habitats; species were identified and the number of individuals observed per species was recorded. Results show that up to a total of 105 different species of birds have been recorded during one day of continuous observations in OPC. A summary of the ten most abundant species observed during 2006, 2007, and 2008 are presented in Figure 2.4.18. A more comprehensive list of bird species that have been recorded for OPC is included in Appendix I.





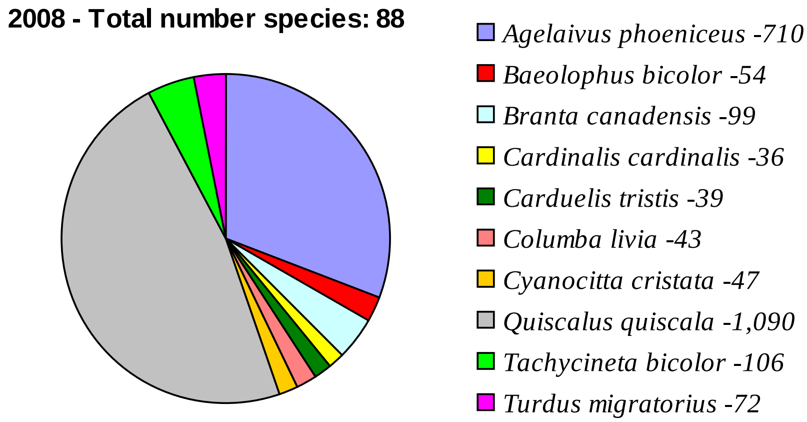


Figure 2.4.18 Species of birds and number of individuals observed during the Bioblitz conducted at the OPC Reserve during 2006-2008.

Another study that is currently under way at the Reserve is the monitoring of secretive marsh birds. Some of these species include *Rallus elegans* (king rail), *Rallus limicola* (Virginia rail), *Porzana carolina* (sora), *Botaurus lentiginosus* (American bittern), and *Ixobrychus exilis* (least bittern). Secretive marsh birds are considered good indicators of wetland ecosystem health; therefore, our interest to monitor these populations within the Reserve. This monitoring effort is part of a national and multi-agency effort developed to monitor marsh bird populations in North America to estimate population trends (Conway 2007). Protocols developed as a result of this national effort are being followed at OPC Reserve and other CBNERR-MD components as well as other National Estuarine Research Reserves implementing similar studies. Details about the sampling protocol are found in the protocol itself (Conway 2007).

The monitoring of secrete marsh birds at OPC started in 2008 and is conducted by Reserve staff and volunteers. Results of observations for 2008 and 2009 show few records of these species in the marsh. During each of both years a total of only six individuals have been recorded, but have included birds from all species of interest at OPC. This monitoring effort will continue as it provides an education/outreach opportunity to volunteers while collecting reliable monitoring data for the Reserve that is simultaneously important for the national survey.

2.4.7.2 Mammals

The OPC marsh lands provide habitat for various species of mammals including *Ondatra zibethicus* (muskrats; Chesapeake Bay Foundation 1984). This marsh area is periodically home to *Castor canadensis* (beaver) which may have contributed log jams to the earlier history of the site. In the OPC Reserve, *C. canadensis* has established in an upstream portion of the Winters Run watershed and can be seen swimming through the high marsh community within the Reserve.

In 2009 a summer intern project was initiated to study the population of *C. canadensis* in and around OPC. The study was three-fold: a survey for *C. canadensis* signs to locate areas in the component that are affected by *C. canadensis* activity, a population survey to estimate the population size, and a tree damage assessment to understand patterns in woody plant damage.

A map of the OPC vicinity shows the locations of *C. canadensis* activity recorded during the summer of 2009. Most *C. canadensis* signs were found in the Bosely Conservancy (Figure 2.4.19), with less activity recorded in the Anita C. Leight property. Activity appears to be concentrated along the waterways. Although *C. canadensis* activity is generally focused near water, the absence of landward activity according to the map is primarily due to the emphasis of time surveying via canoe. Signs (Figure 2.4.20) included scent mounds, slides, damaged trees, lodges, tracks, or a beaver sighting and are indicated by the pushpin symbols on the map in Figure 2.4.19.

Figure 2.4.19 Map of Bosely Conservancy and a portion of the Anita C. Leight property. Symbols indicate the locations of *C. canadensis* signs.

Photo credits: Anita C. Leight Estuary Center

Figure 2.4.20 Signs of *C. canadensis* activity. Girdled and gnawed tree (left) and a beaver lodge (right).

The population survey took place on one evening in August 2009. The surveyors stopped at nine locations along the canoe trail and Turtle Creek to count *C. canadensis*. A total of 24 individuals were sighted with most of the sightings in the upper reaches of Turtle Creek. It is recommended that surveys take place once per month during the summer months to better estimate the population size.

Damage assessments were made to woody species by establishing tree plots and assessing damage within each plot. A total of 16 plots measuring 15 x 9 m (135 m^2 or 443 ft^2) were established mostly around the lagoon areas where much *C. canadensis* activity was noted. It was determined that black cherry trees were damaged most often: nearly 50% of the black cherry trees in the observation plots had signs of *C. canadensis* damage. Approximately 30% of the dogwood, 20% of the green ash, 17% of the pin oak, and 15% of the red maple were damaged. Although river birch was the most common tree species in the plots, only about 8% of these trees were damaged. *C. canadensis* tended to remove black cherry trees that were five inches in diameter or less, leaving stumps in the plots. Larger black cherry trees were not as often removed, but were most often girdled.

Overall, there is little research or monitoring focus on mammals at the OPC Reserve, despite the interest that exist to learn more about this group. The Bioblitz conducted since 2006 at OPC have been used as a way to expand the list of the species found in this Reserve component. To date, a total of 16 species have been listed to occur at OPC (Appendix I).

2.5 DISTURBANCES AND STRESSORS

The history of the OPC watershed has shown evidence of both natural and anthropogenic disturbance. Natural disturbance has been mainly triggered by long-term climate changes and episodic storm events while anthropogenic disturbances have been mainly the result of human development activities (Hilgartner and Brush 2006). The occurrence of disturbances is an important driver shaping the physical environment and as a result the community assemblages found in a particular area. A description of the most prominent natural and anthropogenic disturbances affecting the OPC Reserve is presented in the following sections.

2.5.1 Natural Disturbances

Natural disturbances can be analyzed in terms of the scale and source of the disturbance. The largest scale impacts that shaped the area around OPC are the tectonic history of mountain building and erosion, glaciation, and coastal submergence which provided the layering of unconsolidated sediments at the outer edge of the Piedmont. The main stem of Chesapeake Bay gives evidence of at least three cycles of glaciation, melting, and coastal submergence, forming a temporal sequence of estuaries generally along the same axis but not necessarily the same outline or depth profiles. The present interglacial epoch appears to have flooded the OPC area further inland than the present shoreline. The present shoreline was established solely by quite recent erosion and re-deposition of coastal plain sediments. The fringing marshes played their part in the re-deposition of sediments, but that part was often upstaged by the activities of man in redistributing both soil and vegetation. A fully forested watershed developed which stabilized the movement of water and soil for much of the post glacial, pre-European settlement period. As long as the watershed remained forested the shoreline and marsh community responded primarily to slowly rising sea level. Relatively stable marshes accumulate organic matter in excess of what is needed to respond to rising sea level.

In addition to tectonic history, alternating dry (drought) and wet periods during the past 2,000 years have been documented in the mid-Atlantic region. Extended dry periods were recorded during the seventh century, between 1000 and 1250, 1400, and 1580-1610. In contrast, wet periods dominated during the tenth and fourteenth centuries and between 1610 and 1750 (Brush 1986, Willard et al. 2003 cited by Hilgartner and Brush 2006). Hurricanes and storm events are also important natural disturbances. Although storm events were not particularly recorded for the OPC component, during the past century four significant hurricanes occurred in the upper Chesapeake Bay including the Hurricane of 1933 and Hurricanes Hazel (1954), Connie (1955), and Agnes (1972). Associated impacts with these hurricanes included high floods and significant sedimentation (Landsberg et al. 1968, Vokes and Edwards 1974, Gross et al. 1978 cited by Hilgartner and Brush 2006).

During Agnes in 1972, the occurrence of log jams along the main channel of Winters Run and OPC, as well as other side channels, retarded storm water runoff and periodically flooded a section of the forest. The role that log jams play in changing the hydrology in specific areas as well as their potential impact in fish passage (i.e., blockage of spawning runs) is not well understood and deserves more research. Field observations have indicated, however, that log jams form and dissipate, increase and decrease in size, or move around in the network of channels, which may reduce some of the impacts linked to their presence.

Other natural disturbances are created by biological activity. In OPC, *Castor canadensis* (beavers) have periodically inhabited this area and flooded portions of land behind their dams. A population of *C. canadensis* is established in an upstream portion of the Winters Run watershed and can be seen swimming in the channels within the Reserve. *Cyprinus carpio* (common carp), an introduced species, may contribute to maintaining high turbidity levels in the tidal portion of the wetland through the uprooting of emergent vegetation. The presence of a high population of *C. carpio* in OPC may have an impact on the submerged aquatic vegetation both through increased turbidity and direct consumption.

2.5.2 Anthropogenic Stressors

Among the main stressors currently affecting the natural function and health of OPC's natural resources are those linked to human activities particularly development; the current and potential impacts of invasive species and climate change are also discussed under this section.

2.5.2.1 Development

Historically, anthropogenic disturbances in the OPC Reserve were minimal before the seventeenth century. However, the presence of a charcoal peak within the sediments deposited in OPC during the thirteenth century suggests an increased in wildfires or human-set fires during that time (Hilgartner 1995). Human disturbance accelerated after 1658 when the first European settlers established in the OPC region (Wright 1967 cited by Hilgartner and Brush 2006).

In more recent times, OPC has been heavily impacted and influenced by a rapidly developing watershed. The OPC component sits at the tidal interface of the Bush River and the Winters Run and HaHa Branch tributaries, which contribute the majority of freshwater flow to the system. Urbanization within the Winters Run and HaHa Branch watersheds has been the source of increasing loads of sediment and nutrients being delivered to the estuary. In addition to the strong influence of the upstream area, OPC is also impacted tidally from downstream sources of pollution. There are two wastewater treatment plants that discharge directly into the tidal Bush River and thus have the ability to impact water quality in the OPC area.

Urbanization around the Reserve has included the building of roads, mainly U.S. Route 40, housing development, and the construction of sewer lines, some temporary sewage oxidation ponds, treatment plants and water reservoirs. As a result of these activities, the delivery of nutrients and sediments into the OPC estuary has changed. Although residential development in the immediate vicinity of the OPC component was still light in the 1950s the marsh was expanding rapidly and reached nearly its present extent by 1951. This particular expansion of the marsh could have been related to the construction of the Van Bibber water treatment plant on Winters Run a few miles upstream of the Route 40 crossing. During the 1980's a building boom produced spectacular sediment flows into Winters Run, contributing to sedimentation, high water turbidities and as a result potential impacts to the submerged aquatic vegetation and benthic community.

Development has continued around OPC; new developments of homes and businesses started in the 2000’s on Church Creek (which runs into and meets OPC just before emptying into Bush River), on the northeast corner of Otter Point Road and Route 40, and on the western side of Rt. 40. These and newer developments continued to put significant pressure around OPC increasing the need for protection.

Going hand in hand with development is an increase in impervious surface cover, including the construction of roads, parking lots, roofs, and other human structures. Overall, urbanized areas have larger impervious surface coverage than more rural areas (Figure 2.5.1), and one of the main concerns about impervious surface is that blocks the natural seepage of rain into the ground, which often translates into changes in flow regimes. Subsequently, this runoff is commonly associated with an increased in nutrients, contaminants, erosion, sediment transport, and decreased dissolved oxygen conditions downstream into the estuaries.

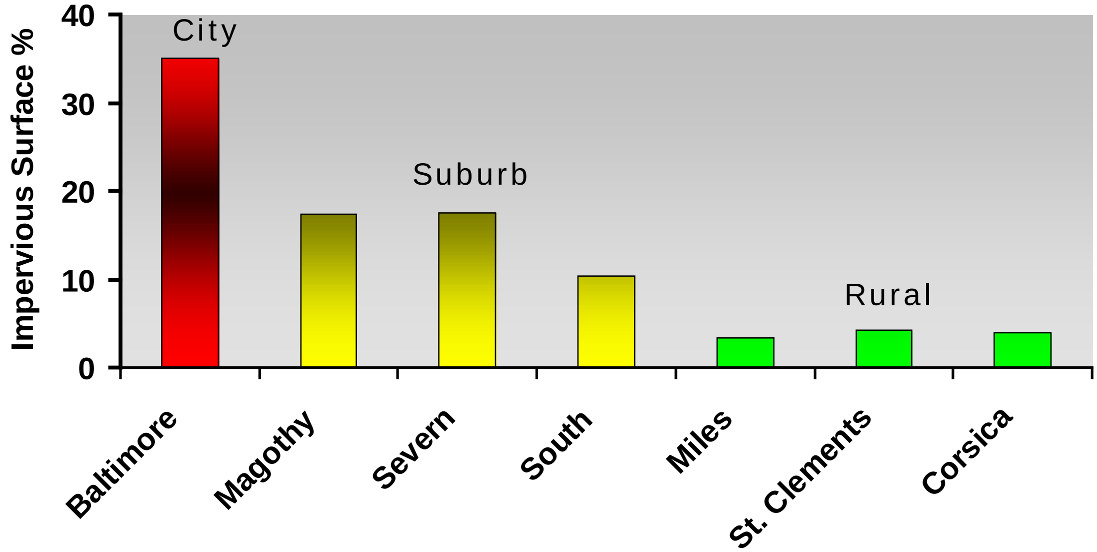


Figure 2.5.1 Relationship between impervious surface and development for various watersheds within the Chesapeake Bay. Source: Uphoff et al. (2008; unpublished data).

The percent of impervious surface cover for the Bush River watershed ranged between 10-30%. These estimated values were based on each 8-digit watershed within the Bush River Basin (MD-DNR and Harford County 2002; Figure 2.5.2).

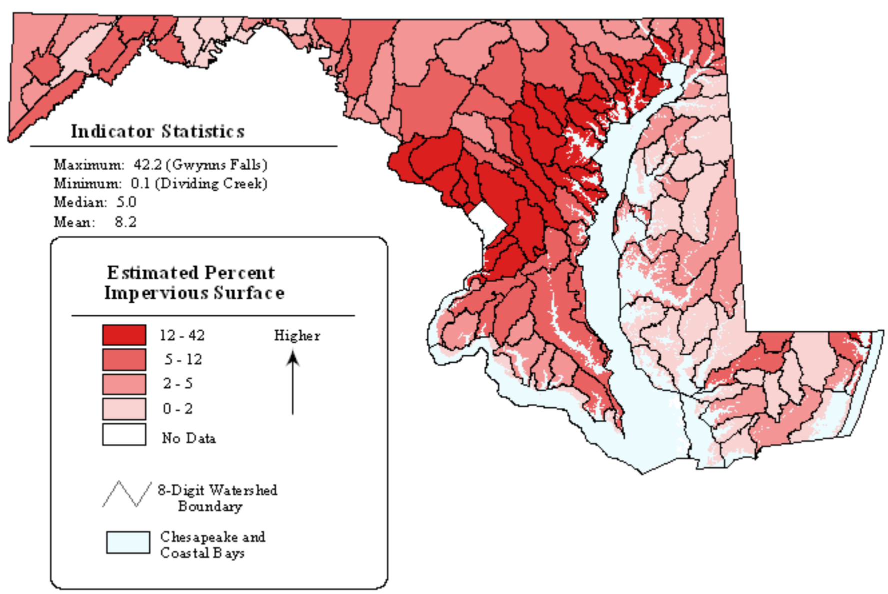


Figure 2.5.2 Percent impervious surface within the Chesapeake Bay. The Bush River watershed falls within the 12-42 % category. Source: Maryland's Surf Your Watershed (http://www.dnr.state.md.us/watersheds/surf/index.html).

Data analyses on fish populations and fish habitat shows that an impervious surface cover above 10% is an indication of watershed degradation. The target level of impervious surface associated with “best” estuarine conditions is generally 5% or less (Uphoff et al. 2008; unpublished data). A study conducted by McGinty et al. 2007 (unpublished data) in the upper Bush River watershed has indicated that bottom dissolved oxygen decreased below critical values (3 mg/l) once percent impervious surface reached more than 10% (Figure 2.5.3). Poor dissolved oxygen conditions could then lead to impacts on fish egg development, which will translate into poor hatching and low survival of pre-adult stages.

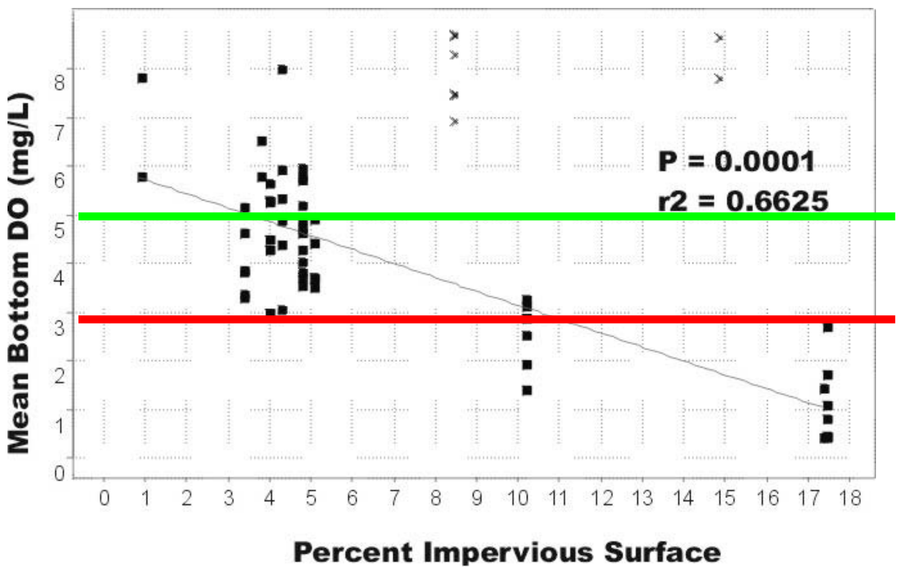


Figure 2.5.3 Representation of the correlation between dissolved oxygen and percent impervious surface. Source: McGinty et al. (2007; unpublished data).

The authors have also shown an overall positive correlation between fish abundance and dissolved oxygen. Fish abundance decreases as bottom dissolved oxygen levels decrease, particularly to critical values (Figure 2.5.4). If other sources of stress also cause low dissolved oxygen levels within inshore areas, the fish community could experience a “habitat squeeze”, caused by low dissolved oxygen values on the bottom and inshore areas. This habitat squeeze restricts the fish populations to the now reduced “good habitat” available.

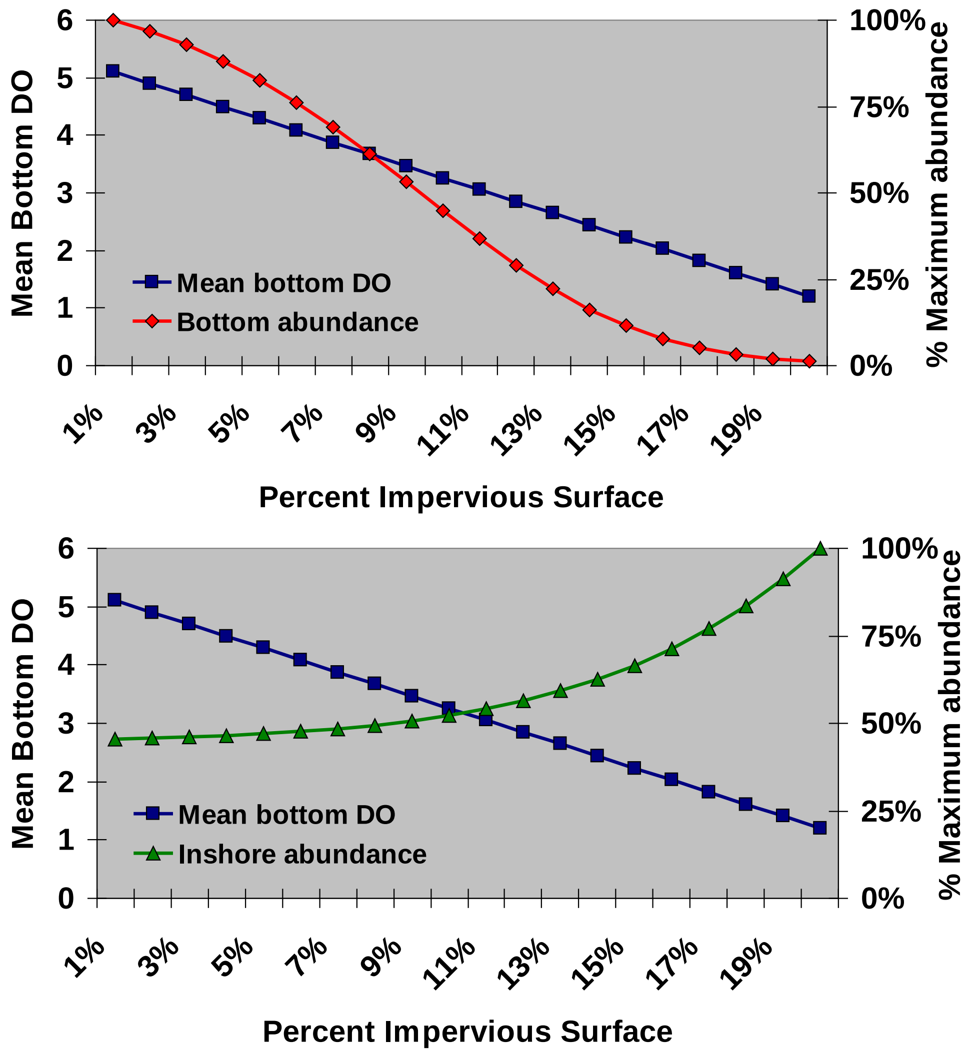


Figure 2.5.4 Representation of the correlation between dissolved oxygen and fish abundance and percent impervious surface. Source: McGinty et al. (2007; unpublished data).

The Maryland Biological Stream Survey has also related the percent of impervious surface in a watershed to the health of aquatic resources. For areas with less than 4% impervious cover, streams generally rate “Fair” to “Good” for both fish and in-stream invertebrates. Areas with 12% or more impervious surface, streams generally rate “Poor” to “Fair” for both (MD-DNR and Harford County 2002). In other words, the impact of impervious surface becomes increasingly significant and negative as the percentage of impervious area increases. Stream impacts related to impervious surface may include reduction of groundwater infiltration, increased soil and stream bank erosion, sedimentation, destabilization or loss of aquatic habitat, and “flashy” stream flows (reduced flow between storms and excessive flows associated with storms).

Historically, other man-made structures (e.g., sewage oxidation lagoons, wastewater treatment plants, and water reservoirs) have induced changes to the physical environment and hydrology of some areas around OPC. During the early 1960s, the construction of two temporary sewage oxidation lagoons at the open water margin of OPC altered the expanding edge of the marsh through the placement of solid fill; their berms, however, provided substrate for high marsh vegetation which would not otherwise grow in this location. During operation, the benthic organisms within the area of the lagoons were subject to intensive eutrophication through the introduction of sewage sludge to the lagoons, which decreased once the lagoons were abandoned. Since their construction water circulation through the lagoons has been limited; although a connection between both lagoons still does not exist, each can be accessed individually by canoe.

The first permanent dam (Atkinson Dam) on Winters Run was constructed by the U.S. Army in 1940s in order to supply water to Aberdeen Proving Ground. No fish passage was ever built at this dam because the region upstream was not considered spawning habitat for *Alosa spp.* (river herrings). Upstream housing development from the dam has resulted in increased siltation which has lead to the complete filling of the dam loosing its function as a water reservoir and as a sediment trap. The frequency of flood events in this portion of the watershed appears to be increasing along with the development of housing in place of farm land (Harold Hartman, 1990, personal communication) in the upper watershed. Although some level of sediment input is necessary to stabilize the marsh in its present extent in the face of rising sea levels, we do not yet know what these maintenance levels are.

A second dam and reservoir for water supply was built near the town of VanBibber downstream of the Atkinson Dam and only a few miles upstream of the present boundaries of the OPC component. This dam was constructed in the 1940s and it was upgraded in 1990 with a fish ladder to allow fish migrations. The reservoir was stocked with juvenile *Alosa aestivalis* (blueback herring) so that they would imprint on the stream segment. The monitoring of returning adults was conducted by MD-DNR Fisheries Service. The results of the first year of monitoring strongly indicated that the new fish ladder was working and that log jams were not hindering the passage of *Alosa spp.* (Jay Odell, 1992, personal communication).

In the document entitled "Bush River Watershed Management Plan" (2003) the watershed was divided into four categories: 1) sensitive subwatersheds which have an impervious cover between 0 and 10%; 2) rurally impacted which have an impervious cover of 0 to 10%, but maybe degraded due to livestock access, grazing and cropping practices; 3) impacted, which have an impervious cover from11-25% and show signs of degradation due to urbanization; and 4) impacted special resource, which have an impervious cover ranging from 11-25%, but also have notable natural resource areas. This includes the OPC drainage.

From a protection point of view, current and future management of the OPC component would need to consider how to mitigate the affects of a rapidly growing population and increased development in the watershed. Increasing sediment and nutrient loads as well as elevated fecal and bacterial concentrations at the site and within the Bush River system are an immediate concern. It should be noted that with the completion of a Bush River Watershed Restoration Action Strategy (WRAS), which represents a partnership between MD-DNR and Harford County, the State of Maryland has focused increased attention on identifying sources of pollutants to the Bush River with the goal of targeting appropriate restoration activities and best management practices.

2.5.2.2 Climate change

Climate change is a global issue that has become of major interest to national and local governments, non-governmental organizations, and the general public over the last 50 years. Charles Keeling of the Scripps Institute of Oceanography (SIO) began monitoring carbon dioxide (CO_2) concentrations at the Mauna Loa Observatory in Hawaii in 1958. Since then, he has published the renowned "Keeling Curve" depicting the drastic change in CO_2 concentrations from 1958 through 2005 (Nisbet 2007). In Maryland, the topic of climate change has become the focus of legislature. On April 20, 2007, Governor Martin O'Malley signed an Executive Order establishing the Maryland Climate Change Commission (MCCC). On August 27, 2009, the MCCC released a Climate Change Action Plan; the report denotes a detailed analysis of climate change in Maryland: the potential causes, impacts, and affects on the Chesapeake Bay, humans, coastline habitats, forests, wildlife, ocean and air temperatures, crops, etc. The Chesapeake Bay is one of the most vulnerable estuaries in the country to the potential impacts of climate change; a result of accelerated sea level rise and land subsidence during the 20th century (Boesch 2008). The location of the OPC Reserve within the upper Chesapeake Bay region makes it vulnerable to climate change related issues including sea level rise, salinity intrusion, and changes in precipitation and temperature patterns.

In Baltimore, Maryland, which is located 18 miles southwest of OPC, sea level is rising at a rate of approximately 3.08 mm yr^{-1} (0.12 in. yr^{-1}); (Figure 2.5.5). The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services equated that to a rise of 0.31 m (1.01 ft.) in 100 years (CO-OPS 2008). Over time, increased water levels would further inundate the marsh edge which could lead to a shifting of plant species less tolerant to flooding toward the interior marsh; thus, resulting in habitat squeeze and competition. As the marshes shift inward, landward barriers have the potential to inhibit marsh shift resulting in wetland deterioration (Scavia 2002).

Currently, the freshwater plant species dominating the intertidal marsh edges of the Reserve are *Nuphar lutea* (yellow pond-lily or spatterdock), *Pontederia cordata* (pickerelweed), *Peltandra virginica* (arrow arum), and *Sagittaria latifolia* (arrowhead). While these intertidal species are are accustomed to intermittent flooding, increased inundation may cause waterlogging and plant death (Scavia et al. 2002). Increased flooding and loss of plants will also yield greater shoreline erosion. The OPC marsh is a shallow system; therefore, loose sediments could increase turbidity resulting in the degradation of water quality, loss of SAV, and impacts to other aquatic organisms.

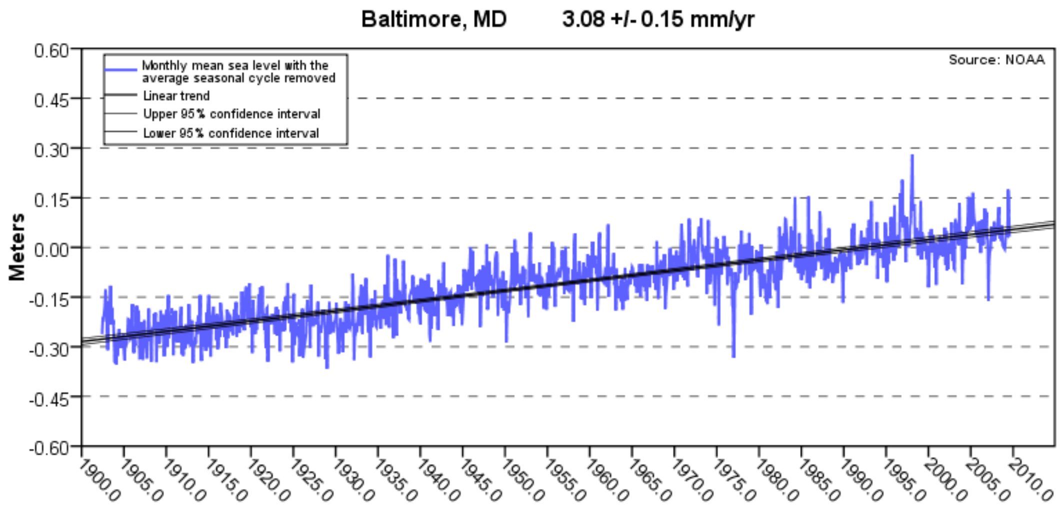


Figure 2.5.5 Average sea level rise in Baltimore, Maryland from 1900-present. Source: CO-OPS - Center for Operational Oceanographic Products and Services (2008).

Salinity intrusion, a result of sea level rise, may pose an additional threat to the tidal freshwater marshes of OPC, where the average salinity falls below 1 part per thousand. Wetlands can typically tolerate gradual changes in salinity as freshwater marshes are replaced by brackish marshes; however, freshwater plants are not as tolerant of irregular and unpredictable salinity pulses. Some species become salt burned, stunted, grow at reduced rates and/or exhibit reduced carbon assimilation (Scavia et al. 2002). Species composition and diversity at the Reserve may also change as the marsh gradually shifts to a more brackish habitat. Furthermore, methanogenesis, which is the common pathway for cycling carbon among tidal freshwater marshes, would also be impacted by a salinity increase. The cycling of carbon yields organic matter accumulation, thus the accretion of sediments. Salinity intrusion increases the availability of sulfate (SO_4^{2-}). The increased availability of sulfate reduces the methanogenesis pathway and increases sediment organic matter mineralization or decomposition further slowing the accretion of marsh sediments; therefore, reducing the potential to keep pace with sea level rise (Weston 2006).

The ability of a tidal freshwater marsh, like the one in OPC, to keep pace with sea level rise would ultimately depend on a balance between the potential impacts and the mitigating factors for those impacts. A general representation of this concept is given in Figure 2.5.6 (Delgado 2010, unpublished data). Considering salinity intrusion and increased flooding as the main impacts of sea level rise, the OPC marshes would probably be more vulnerable to salinity intrusion. This system currently receives a significant amount of sediments from adjacent subwatersheds, in addition to in situ organic matter deposition from plant material that supports a positive surface elevation change probably sufficient to keep pace with estimated values of sea level rise.

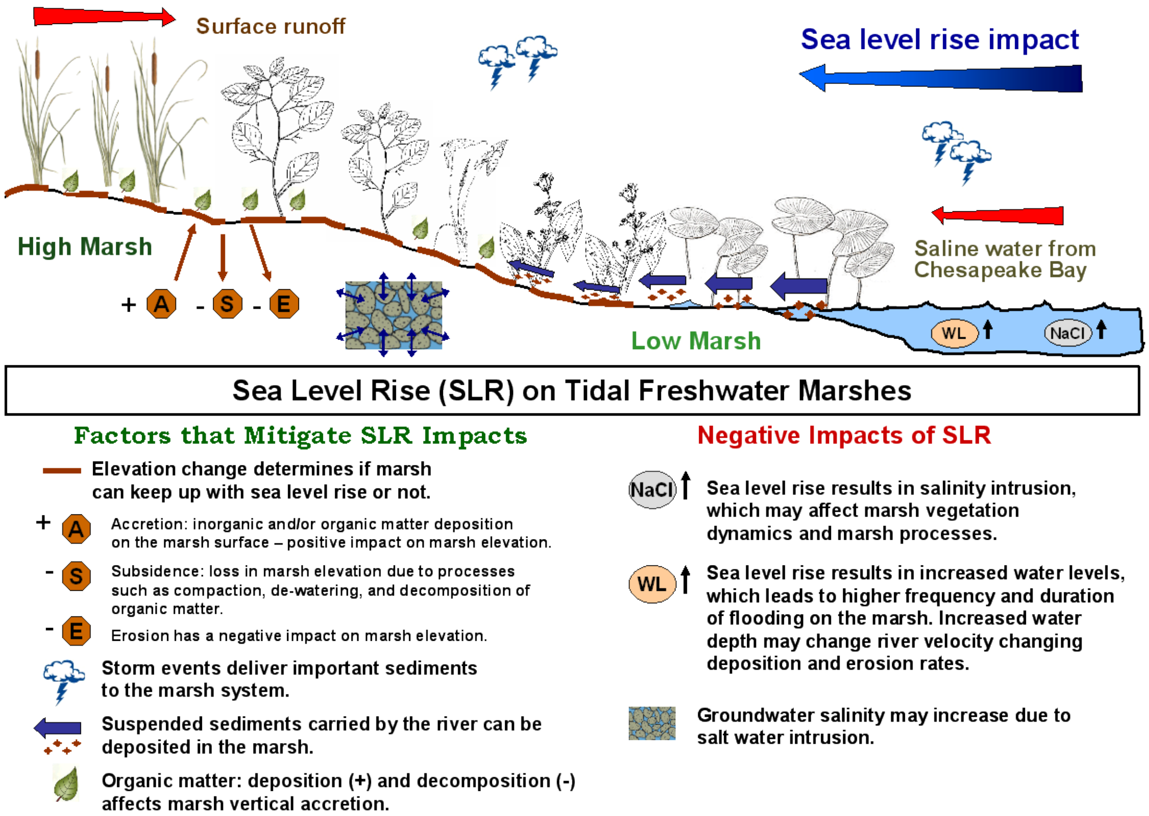


Figure 2.5.6 Diagrammatic representation of the potential impacts of sea level rise and mitigation factors on tidal freshwater marshes. Source: Delgado et al. (2010, unpublished data).

Temperature changes associated with global climate change may also translate into changes in the structure and functioning of plant communities among OPC marshes. Mean temperature for Maryland is expected to increase by 3 °F by 2050 (Boesch et al. 2008). Extreme changes in the temperature regime can cause plants to move northward or to higher elevations and affect reproduction and growth rates. The plant hardiness zonation changes illustrated by the differences between the 1990 and 2006 maps demonstrate plant zone shifts as a result of warming temperatures (Figure 2.5.7; Arbor Day Foundation, 2010). During this time period, some regions of Maryland experienced an entire zone change. As global climate change continues, the hardiness zones may continue to move northward, and plant communities will continue to respond to those changes.

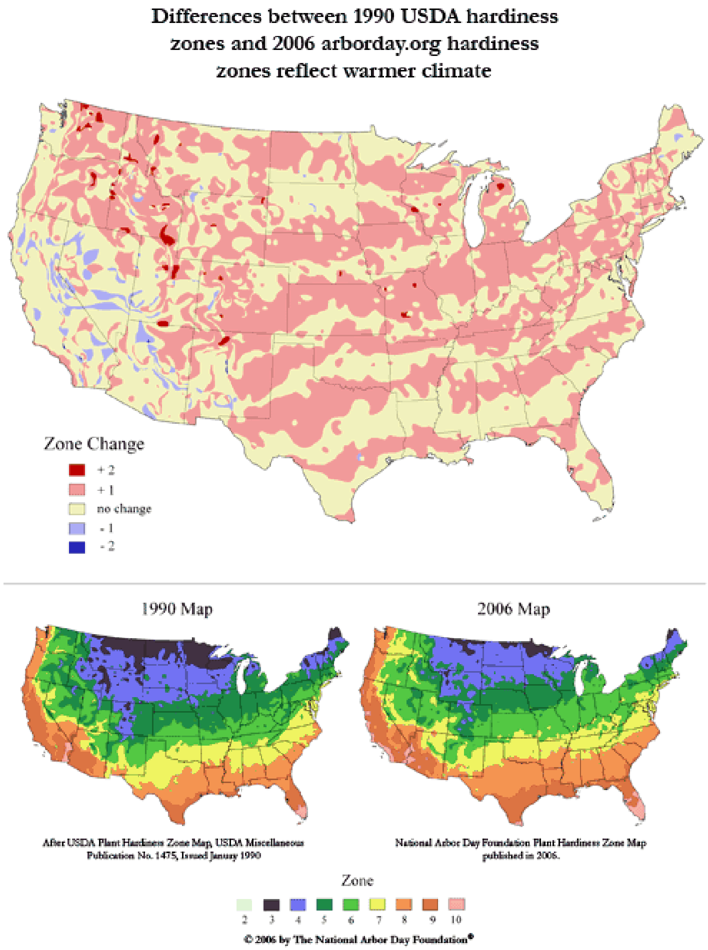


Figure 2.5.7 Differences between the plant hardiness zone maps of 1990 and 2006. Source: Arbor Day Foundation (2010).

Also related to climate change, precipitation is likely to increase during the winter and spring, but become more episodic. The warmer temperatures will increase evaporation and likely yield more droughts during the summer months. These alterations in the hydrological regime will yield unpredictable run-off inputs of sediment and nutrients, thus modifying habitat suitability. In the aquatic environment, vegetation adapted to the changing conditions will likely replace resident marsh plants and non-native species are likely to find the modified conditions more favorable (Poff et al. 2002). Furthermore, Chesapeake Bay water temperatures have been increasing at a rate of 0.4 ° F per decade since 1938 equating to an overall warming of 2.8 °F through 2006 (Figure 2.5.8; Boesch et al. 2008). Though difficult to predict, the rise in water temperatures are likely to enhance storm events. Future hurricane frequency for the mid-Atlantic region is unknown; however, with a minimum 2.2 °F rise in water temperature, storm wind strength increases of approximately 5-10% are probable. The combination of higher sea levels and more intense winds make shorelines more vulnerable.

Under a scenario of more frequent and stronger storms, the OPC system is likely to be affected by storm surges and wind speeds that could impact the marsh flora and fauna. Storm surges may bring excess sediments and "wrack" that accumulate among marsh surfaces and suffocate underlying vegetation. Erosion of organic matter and intrusion of salt water also cause salt burn and vegetation death. Low salinity marshes do have the ability to rejuvenate after severe storms; however, it is case dependent (Guntenspergen et al. 1995).

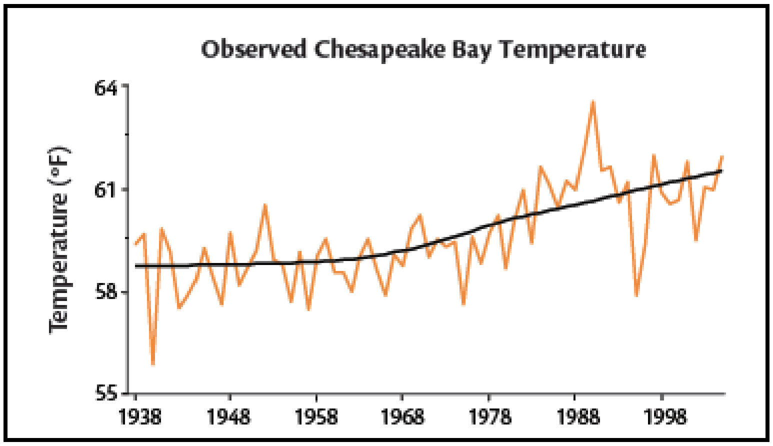


Figure 2.5.8 Annual Chesapeake Bay Temperatures recorded at Solomons Island Laboratory from 1938-2006. Source: Boesch et al. (2008).

Currently, CBNERR-MD is conducting a series of long-term projects to monitor weather, water quality, submerged aquatic vegetation, groundwater, wetland surface elevation, marsh emergent vegetation as well as other flora and fauna at OPC and the other Reserve components. This is part of a national effort lead by NERRS to designate National Estuarine Research Reserves as a network of sentinel sites for the detection and monitoring of climate change impacts on coastal ecosystems (Wasson et al. 2009). This effort will provide important baseline information to evaluate changes and system responses not only to climate change, but to land use changes, to evaluate success of restoration projects, to monitor introduction or expansion of invasive species, etc.

2.5.2.3 Invasive species

Invasive species represent an issue of major concern in natural systems because of their tendencies to proliferate quickly and displace native species. In the Chesapeake Bay there are approximately 200 known invasive species. As of 2001, 46 of the invasive species have been labeled as a "nuisance" and of those, six are extremely threatening to the Bay ecosystem: *Cygnus olor* (mute swan), *Myocastor coypus* (nutria), *Phragmites australis* (common reed), *Lythrum salicaria* (purple loosestrife), *Trapa natans* (water chestnut), and *Dreissena polymorpha* (zebra mussel);(Chesapeake Bay Program 2009). At the OPC component, there are 22 known invasive species (Table 2.5.1). These species are not labeled invasive solely because of their non-native origin, but because they are causing an overall problem for the native plant and animal communities.

Table 2.5.1 Invasive species currently found at Otter Point Creek Reserve.

Order	Family	Scientific Name	Common Name	Status
BIRDS				
Anseriformes	Anatidae	*Branta canadensis*	Canada goose	P
		Cygnus columbianus	Tundra swan	R
		Cygnus olor	Mute swan	P
Passerformes	Passeridae	*Sturnus vulgaris*	European starling	P
HERBACEOUS PLANTS				
Asterales	Asteraceae	*Taraxacum officinale*	Dandelion	P
Capparales	**Brassicaceae**	***Alliaria petiolata***	**Garlic mustard**	**A**
Cyperales	Poaceae	*Agrostis stolonifera*	Creeping bentgrass	U
		Microstegium vimineum	**Japanese stiltgrass**	**A**
Dipsacales	Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle	P
Liliales	Liliaceae	*Hemerocallis fulva*	Day lily	P
		Lilium superbum	Turk's cap lily	P
Myrtales	Lythraceae	*Lythrum salicaria*	Purple loosestrife	R
Typhales	Typhaceae	*Typha angustifolia*	Narrow-leaved cattail	P
Urticales	Cannabaceae	*Humulus japonicus*	Japanese hops	P
WOODY PLANTS				
Celastrales	**Celastraceae**	***Celastrus orbiculatus***	**Oriental bittersweet**	**A**
Dipsacales	**Caprifoliaceae**	***Lonicera japonica***	**Japanese honeysuckle**	**A**
Rosales	**Rosaceae**	***Rosa multiflora***	**Multiflora rose**	**A**
Urticales	Moraceae	*Morus alba*	White mulberry	R
SUBMERGED AQUATIC VEGETATION				
Halorgales	Halorgaceae	*Myriophyllum spicatum*	Eurasian watermilfoil	P
Hydrocharitales	**Hydrocharitaceae**	***Hydrilla verticillata***	**Hydrilla**	**A**
Najadales	Najadaceae	*Najas minor*	Spiny naiad/brittle waternymph	R
	Potamogetonaceae	*Potamogeton crispus*	Curly pondweed	R
Key: A = Abundant; P = Present; R = Rare; U = Unknown				

The underwater grass *H. verticillata* is one of the most predominant of all of the invasive species that have been introduced into OPC. *H. verticillata* is native to Southeast Asia, first appearing in Florida in the 1960's and in the Potomac River near Washington D.C. in 1982 (MD-DNR 2010). The first sample of *H. verticillata* was collected at the Reserve in 2001 and by 2002 it was the second most abundant SAV species in this site (Engelhardt et al. 2006). The spread of *H. verticillata* and other invasive SAV species have been monitored since 2008 among five sites within OPC through sampling efforts that are conducted every field season. Information and preliminary results about this effort is presented in section 2.4.1.1.

While the term invasive species generally has a negative connotation, research has determined that *H. verticillata* may have some positive influences. In the Potomac River, *H. verticillata* has assisted in slowing water velocity, stabilizing sediment, providing food for waterfowl, and increasing the removal of particulates thus clarifying turbid water. The improved water quality of the Potomac River facilitated the spread of natives; *H. verticillata* and native species biomass values were positively correlated (Rybicki and Landwehr 2007). Similar effects have been observed at OPC where *H. verticillata* improves water quality during the growing season which may then promote the gradual re-establishment of native species.

P. australis, common reed¸ has increasingly become a threat to the OPC marshes. The invasive *P. australis* strains originated from Europe and Asia; however, there are *P. australis* strains native to the U.S. The invasive strain has been speculated to have invaded the U.S. during the late 1700s via the shipping industry (Thompson 2003). Furthermore, one of the main uses in Europe was for thatching roves and it was brought to the U.S. for the same purpose (Webster 2009, personal communication). Aerial surveys conducted by the United States Fish and Wildlife Service Chesapeake Bay Field Office (USFWS CBFO) within the Chesapeake Bay watershed from 1995 to 1997 depict the intensity of the *P. australis* invasion; it was determined to be very prominent among most of the Chesapeake Bay marshes (Thompson 2003). The largest extent of *P. australis* in natural marshes occurred on the lower Eastern Shore from the Nanticoke River south to the Pocomoke River, the Eastern Bay and Chester River area, Baltimore Harbor, C&D Canal, and Aberdeen Proving Grounds (Thompson 2003; Figure 2.5.9).

Research conducted within the Chesapeake Bay has shown that *P. australis* is more abundant and produces the greatest amount of viable seed in subestuaries characterized by larger anthropogenic development (King et al. 2007, Silliman and Bertness 2004). This is a major concern in OPC, as this is a Reserve site surrounded by highly developed land, which might accelerate the invasion of *P. australis* into the entire marsh area. In the Rhode River subestuary, for example, the number of *P. australis* patches increased from 5 to more than 200 in about 35 years and many of these occur in undisturbed wetlands; the source of seeds for these new patches has originated from older patches located in disturbed areas ((McCormick et al. 2010).

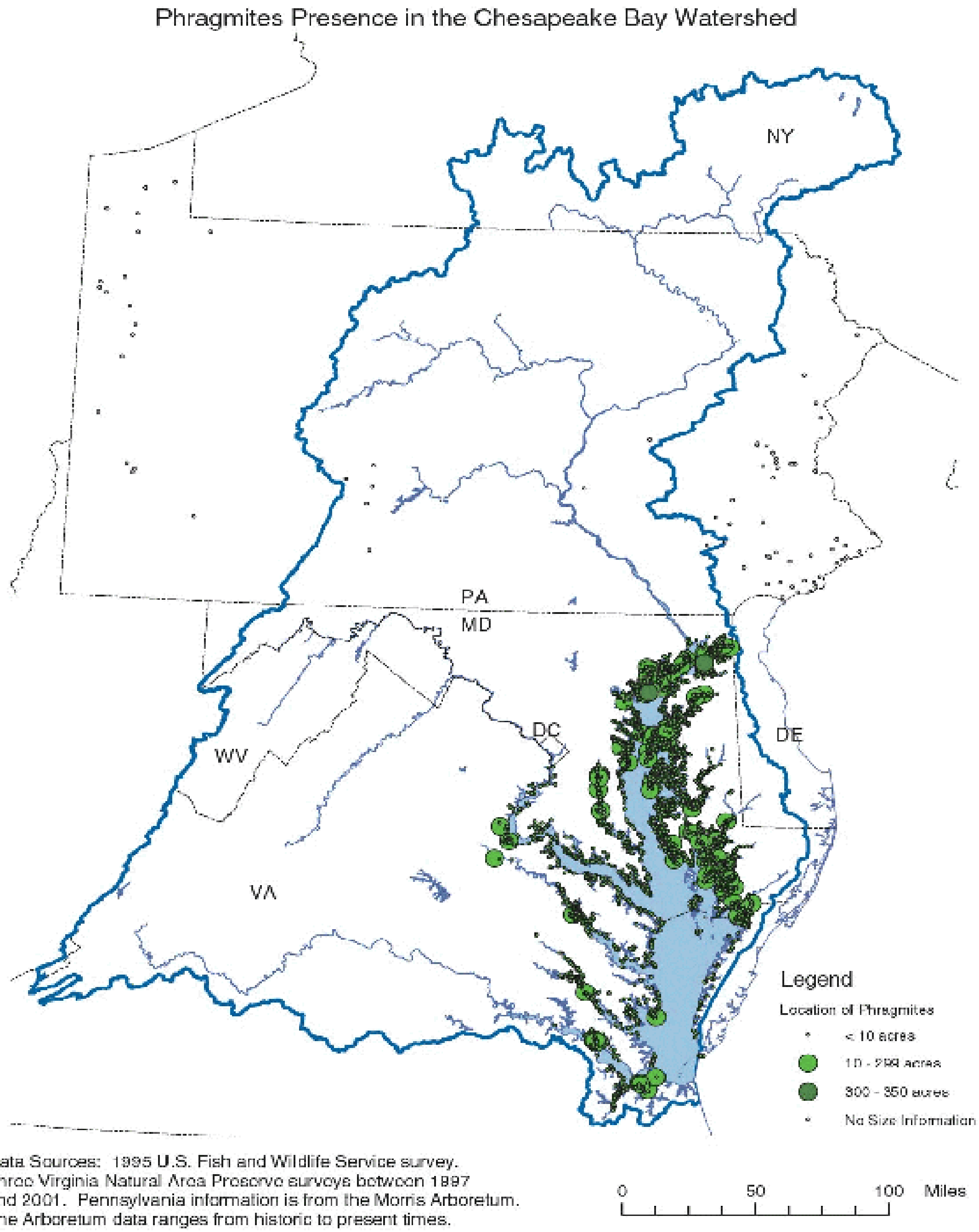


Figure 2.5.9 Presence of *P. australis* in the Chesapeake Bay watershed. Source: Thompson et al. (2003).

It is unknown when *P. australis* first appeared in OPC; however, according to an aerial photograph taken in 1991 it comprised 0.4% of the entire 1.39 km^2 (0.54 mi^2) OPC wetland (Hilgartner 1995). In July of 2008, a collaborative effort between CBNERR-MD and The National Aquarium in Baltimore mapped most of *P. australis* stands in the OPC marsh. The survey estimated approximately 3,000 m^2 (0.7 acres) of *P. australis* within this component

(Figure 2.5.10); although the actual number might be between 4,046–6,070 m^2 (1-1.5 acres) as some patches remain to be mapped. *P. australis* is characterized as a problematic species because it aggressively forms dense monocultures, decreases species diversity, provides little food and shelter for wildlife, and is very hard to control (Thompson 2003). It is very difficult to eradicate because it forms below ground roots and rhizomes. Mowing prior to seeding will remove the above ground plant matter and control small stands, but mowing will not kill the plant. Herbicide application is the most effective method for killing the plant; however, it is also the most costly.

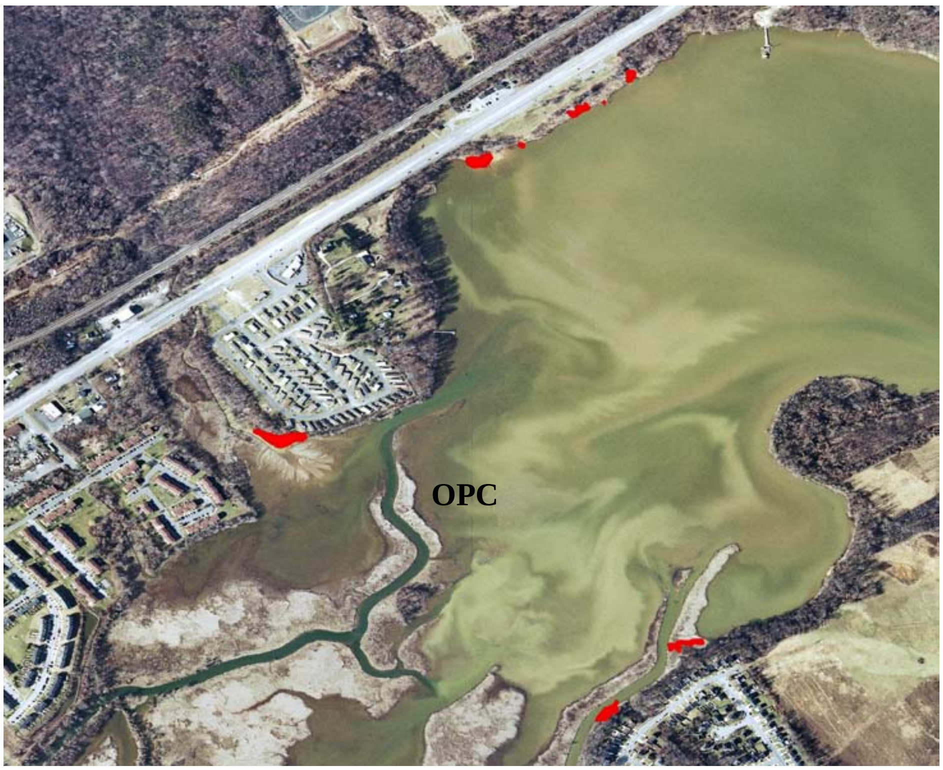


Figure 2.5.10 Map of *Phragmites australis* stands in OPC. Created by Jeff Campbell (2009).

To date, there has been no removal of *P. australis* at OPC Reserve; however, it is currently being monitored to determine if the stands are expanding. Like other invasive species, *P. australis* also has some potential benefits for the ecosystem. The rhizomes and roots assist in soil stabilization and accretion potentially combating sea level rise. The sediment trapping rate of *P. australis* is 34 g m^2 day^{-1} while *Spartina spp.* traps 8 g m^2 day^{-1} (Rooth 2000). *P. australis* has a high tolerance for various environmental conditions and levels of disturbance; therefore, it is found in areas where other plants can not survive. Lastly, *P. australis* cycles excess nutrients thus enhancing water quality.

L. salicaria – purple loosestrife – is a notorious invasive species among the Jug Bay marshes, but it is only a potential threat in OPC. *L. salicaria* is native to Europe first appearing in the United States in the early 19^{th} century. Seeds were transported within the ballast of ships and within the wool of European sheep. It is currently found in all of the lower 48 states, except for Florida. *L. salicaria* is problematic because of its tendency to create dense monocultures, thus shading and out competing native species (Kyde 2008). *L. salicaria* is actively monitored at the OPC component by a group of volunteers called "The Invasinators;" and removal and control of *L. salicaria* is one of their main objectives. In July 2008, "The Invasinators" set out to remove all *L. salicaria* stands within the OPC marshes; however, the species was not found. In an effort to avoid the introduction of this species, its presence will continually be monitored in OPC.

"The Invasinators" also focus on the removal of *Rosa mulitflora* (multiflora rose), *Celastrus orbiculatus* (Oriental bittersweet), *Lonicera japonica* (Japanese honeysuckle), *Morus alba* (white mulberry), *Microstegium vimineum* (Japanese stiltgrass), *Humulus japonicus* (Japanese hops), and *Alliaria petiolata* (garlic mustard). The presence and potential expansion of invasive species in OPC marshes are monitored through CBNERR-MD's marsh emergent vegetation monitoring projects. Currently, there is not an effort solely designed to monitor invasive species in the Reserve, and it represents a need for future efforts. It is important to continue efforts to monitor and map the spread of all the invasive species in order to determine their potential threat to the OPC component's ecosystem health.

2.6 RESEARCH AND MONITORING

Good progress has been made to continue and initiate new research and monitoring projects; however, there is still much that needs to be done to better characterize and understand the natural dynamics, status, and system responses to the changing environment of the OPC Reserve natural communities.

Most existing and new research and monitoring efforts would be designed to accomplish the short and long-term goals and objectives specified in the Reserve's research and monitoring plan. Because of the scale, this effort would entail the necessary coordination and collaboration with both existing and new partners. An example of the need to maintain such partnerships is demonstrated by the recent establishment of the Bush River Partnership, involving Reserve staff and local and State partners, in an effort to address many of the issues currently affecting the Reserve, adjacent watersheds, and the Bush River in general. As part of this partnership, a research and monitoring workgroup is working to identify research needs and priorities as well as effective ways to fulfill those needs. This effort started in 2007 and it is expected to grow as more partners are identified and join the effort.-

In addition to working with partners, the Reserve Research Program will actively engage with academic and other research institutions to foment their interest in conducting projects that will address research needs within the Reserve. Volunteers have always played an important role in the collection of field data, particularly as part of monitoring projects. This relationship would be strengthened by providing more opportunities for training, direct involvement with the planning, collection, and analysis of data, and delivery of information to appropriate audiences.

In an effort to increase available resources to conduct research within the Reserve and adjacent watersheds, the Research program will pursue available grants in collaboration with partners. The

NERRS Graduate Research Fellowship program will continue to provide additional opportunities to address research needs within the Reserve.

2.6.1 Research Facilities

The major research facility located at the OPC Reserve functions in the Anita C. Leight Estuary Center in Harford County's Leight Park. This Center provides facilities that can be used by the Reserve program to successfully implement its research and monitoring programs. Some of these facilities and resources include office space (with available wireless connection), laboratory space, storage area, and water access facilities, such as piers, docks, and ramps. A boat and motor, canoes, and kayaks are also available to conduct research and monitoring programs.

2.6.2 Research and Monitoring Needs

Current research and monitoring activities at OPC Reserve are focused on characterizing and assessing the current ecological state of the natural resources in this component as well as monitoring changes over time. The Reserve Research Program is implementing efforts to obtain baseline information and long-term monitoring data of SAV and marsh emergent vegetation communities. This type of monitoring, in addition to ongoing water quality monitoring, is important to detect changes in the component's natural resources due mainly to climate change, development, and land use changes. In addition to this, a better understanding of the ecology and interactions among the different plant and animal communities found in the Reserve is much needed. A description of main research needs organized by biological component is presented in the following sections.

2.6.2.1 Tidal freshwater marshes

Some research and monitoring is already occurring to characterize OPC tidal freshwater marshes and their response to climate change, development, and land use. There are still, however, some information gaps that need to be fulfilled. Some of these include the development of a sediment mass balance including a grain size distribution and a hydrologic budget with both surface and ground water components. One component of the sediment budget will probably include the activities of bioturbing organisms, such as carp. Related to sediment dynamics, it is important to determine marsh surface elevation change within different plant communities and hydrological regimes to better understand their response to climate change, particularly sea level rise. More studies to assess the presence and concentration of heavy metals and toxic elements in marsh sediments are also necessary.

The creation of a nutrient budget that accounts for inputs and outputs from the watershed (as a result of different land uses) and within the system is of great importance to better understand marsh functioning and its relationship with water quality. This information is also valuable to populate nutrient loading models used to generate projections of the impacts of environmental changes and watershed land use changes in water quality.

In addition to ongoing monitoring efforts, more research is necessary to study the population dynamics of the submerged aquatic vegetation communities at OPC, particularly regarding their role in sediment retention (e.g. *H. verticillata*), nutrient cycling, water quality, nursery habitat, food source, etc. Studies of seed banks, and flooding and salinity tolerances of OPC emergent wetlands are also needed to better understand their potential responses and resilience to environmental changes, particularly those related to increased flooding and salinity intrusion linked to sea level rise.

At a broader scale, the development of GIS projects, particularly habitat mapping and change analyses, will be vital for determining the impact of development and land use changes on OPC Reserve aquatic and upland resources.

2.6.2.2 Upland vegetation community

Information available on the OPC upland vegetation community is limited. Basic species listings are not complete and there is a need for a basic understanding of their function particularly under projected environmental and climatic changes, for example regarding carbon sequestration, primary productivity, nutrient cycling, natural regeneration, etc.

The geographic location of the OPC component on the northern edge of the Southern Forest Region and the southern edge of the Eastern Deciduous Forest Region leaves the site open to biological invasions from either region. The main impacts of invasive species in these communities and the severity of their presence is not well known, despite its importance if any attempt to control them is to be implemented. In order to manage for species diversity and to preserve the characteristic biota of the OPC component it will be necessary to monitor the vegetation periodically to detect impacts of introduced species.

Besides some general observations on the sites's vernal pool, there have not been concrete studies conducted on this community. Some needed information include a characterization of the vernal pool's physical and biological parameters, hydrological cycle, and its role as habitat and reproductive site for various organisms. Considering the sensitivity of vernal pools to climatic changes, it is important to develop a long-term monitoring plan that would allow the detection of changes.

2.6.2.3 Microbiological components

Any research and/or monitoring effort to study the microbial communities within OPC, particularly with respect to its wetlands, would be a new addition to the almost lack of existing information on these communities. Current water quality monitoring efforts conducted by the Reserve do not include the sampling of fecal coliforms. Considering the health issues associated with their presence, it will be an important component to add to the suite of parameters currently being analyzed.

2.6.2.4 Plankton

Although considerable information is available about the plankton communities of different areas of the Chesapeake Bay, not much is known about the particular communities within the OPC component. Basic studies are needed to determine the species composition, abundance, biomass, and productivity of the phytoplankton and zooplankton communities in this area. Further research is also needed to determine the interrelationships between Reserve plankton components and water quality, physical and chemical environmental factors, and the local food web.

Long-term monitoring is needed to determine the spatial and temporal trends in species composition and abundance, shifts due to invasive species, and to evaluate the plankton community's responses to potential climate and land use changes. Monitoring of potentially harmful phytoplankton species is particularly important.

2.6.2.5 Benthic macroinvertebrates

The benthic community at the OPC component has not been the focus of much research. A first priority is to conduct a comprehensive baseline characterization of this community including species composition and abundance in different substrates and locations within the estuary (including ponds and flooded forest areas). Aquatic insects and benthic invertebrates constitute food supply for wood ducks and there is limited knowledge of what is there or their relative abundances.

Establishing a long-term monitoring effort in both the marsh and the open water regions is important to determine natural spatial and temporal population changes and to evaluate the potential responses to anthropogenic and natural stressors. Of major importance in this area are the potential impacts from increased development, particularly those that may result after the full implementation of the Base Realignment and Closure (BRAC) plan in Harford County. Monitoring is also valuable to detect the presence of invasive species and community shifts as a response to climate change.

2.6.2.6 Fish, reptiles, and amphibians

The marshes of OPC provide important habitat for many different species of fish, including some of economic importance for the region such as white and yellow perch. In spite of the information that has been gained through ongoing volunteer-driven fish monitoring efforts in OPC, there is still a need to better characterize the fish populations in this estuary. A comprehensive initial survey of species presence and relative abundance among different habitats and conditions would provide valuable baseline information for comparative or change analyses studies.

An ongoing monitoring effort using telemetry to study turtles at OPC have provided some information about this organism including habitat use and range; additional research should include the study of other reptiles and amphibians (including snakes, salamanders, and frogs and toads) found at different OPC habitats, including the vernal pool. Projects may include the study of population dynamics, habitat use, feeding habits, etc.

2.6.2.7 Birds and mammals

Studies of specific bird and mammal species occurring at OPC Reserve do not exist or are very limited. Therefore, any studies would add to the natural history of this site. How different species of water birds make use of the wetlands throughout the year, which are the feeding sources and habits of different water birds, which is the population size and reproductive success of *Pandion haliaetus* (osprey) nesting at OPC are some questions that could be answered with basic research projects.

Little is known about the beaver population at OPC. Learning more about this group, its population density, feeding habits, and habitat use, is important as they seem to play an important role in the local wetland hydrology.

2.6.2.8 Other research and monitoring needs

Current trends in surface and ground water withdrawals throughout Harford County show accelerated increases. These will have to be monitored to provide early warning of potential biotic changes and the resiliency of the ecosystem to the occurrence of drought, particularly under current climate change trends. Excessive water withdrawals have the potential for lowering the surface of the unconfined aquifer. Surface water table changes of a few inches to a few feet can, if they persist, eliminate some species and encourage the establishment of others. Changes in the insect and vertebrate populations inevitably follow changes in vegetation. Thus the whole character of the wetland can be altered unless careful monitoring of water levels leads to management actions to preserve necessary flows.

Additional research and monitoring needs identified for each of the Reserve components are listed in Appendix J of the CBNERR-MD management plan (Maryland DNR 2008).

CHAPTER 3. THE ECOLOGY OF THE JUG BAY ESTUARY

3.1 OVERVIEW

Jug Bay was designated as a component of the National Estuarine Research Reserve in Maryland (CBNERR-MD or Reserve) in July, 1990. It is one of three components of the Reserve (Figure 3.1.1). It encompasses 837 hectares (2,068 acres) of wetlands, open water, and terrestrial habitat. The site is at Latitude 38° 76’ North and Longitude 76° 69’ West. It is comprised largely of tidal freshwater wetlands in the Patuxent River floodplain located to the south and east of Washington, D.C. Several streams including Two-run Branch, Galloway Creek, and Pindell Branch run through the component into the Patuxent from the eastern bank. Mattaponi Creek and the Western Branch of the Patuxent empty into the river from the western shore (Figure 3.1.2). This system of waterways provides important functions such as sediment capture, nutrient cycling, shore stabilization, water purification, and flood control. The Patuxent River itself is an oligohaline system dominated by freshwater inputs. The salinity at Jug Bay is very low (usally under 0.5 ppt).

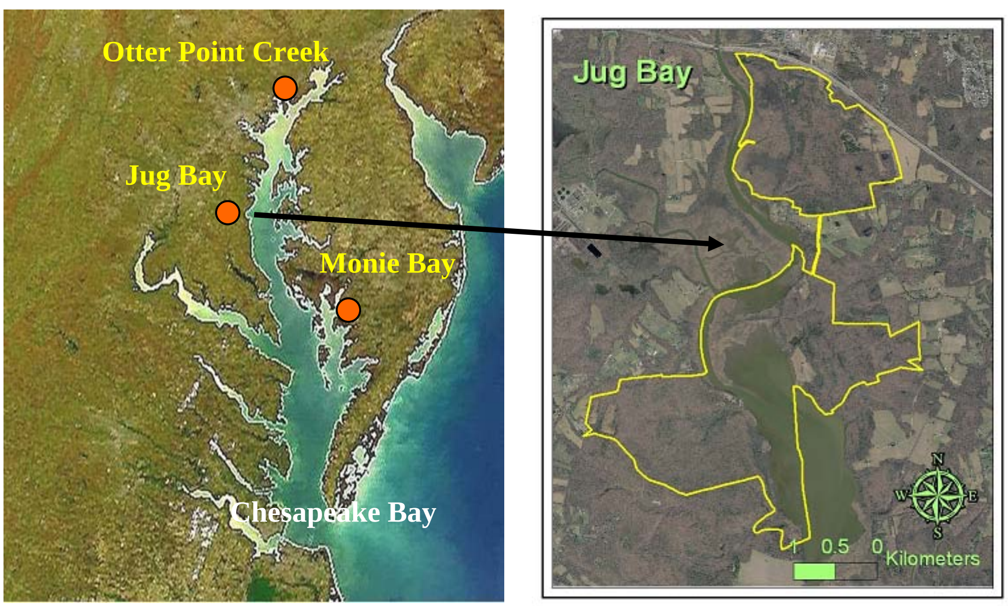


Figure 3.1.1 Geographic location and boundaries of the Jug Bay component of the Chesapeake Bay National Estuarine Research Reserve in Maryland.

An important component of the Jug Bay system is the tidal freshwater wetlands. Approximately 251 acres (102 hectares) of the park are subtidal and open water. Other habitats present at the component include mudflats, low marsh, middle and high marsh, scrub-shrub, forested wetlands, forested uplands, and fields. The wetlands are ecologically important as critical habitat for wildlife, fish, and plants, and serve as a transition zone between the tidal brackish marshes downstream and the non-tidal freshwater marshes upstream. Jug Bay is among the largest tidal freshwater systems in the eastern United States (Boumans et al. 2003). Tidal freshwater marsh systems are considered globally important because they contain rare habitat. Owing to the varied habitats, a high diversity of organisms is found at Jug Bay including submerged and emergent aquatic vegetation, upland plants, aquatic invertebrates, fish, mammals, birds, reptiles and amphibians.

The component is approximately 43 river-miles from the Chesapeake Bay and 20 miles east-southeast of Washington, D.C. There is low topographic relief at the site and the freshwater streams (Figure 3.1.2) that feed into the component meander through farmland, forest, suburban and urban areas slowly making their way to the Patuxent River. Water quality at the site is driven in part by the vast tidal freshwater marshes that have the capacity to help reduce nutrients and aid in biological processing at the site. Additionally, water quality is influenced by the rapid movement of water and tidal flux associated with the main stem of the Patuxent River.

Figure 3.1.2 Location of main creeks flowing into the Patuxent River, within or near the CBNERR-MD Jug Bay component. The white dot indicates the mouth of the creek.

Threats to the Jug Bay component include population growth and land use changes within the Patuxent River watershed. Additional development in the vicinity of Jug Bay could have significant impacts on the ecosystem. The Patuxent River has been characterized as moderately eutrophic due to large inputs of anthropogenic sources of nitrogen and phosphorus from wastewater treatment plants, agricultural fertilizers, urban/suburban runoff, residential leach fields and atmospheric deposition. The water quality in Jug Bay is heavily influenced by the Western Branch wastewater treatment plant in Upper Marlboro that discharges about 20,000,000 gallons of treated effluent per day into Western Branch, a tidal tributary of the Patuxent River with confluence directly into the Jug Bay component. The addition of hardened shorelines upstream of Jug Bay has changed the hydrology compared to historic conditions. Invasive plant and animal species, such as resident Canada geese and Asian carp, are constant threats to the natural communities.

There are two key partners for the Jug Bay component: the Jug Bay Wetlands Sanctuary (Anne Arundel County Department of Recreation and Parks), and Patuxent River Park (Maryland-National Capital Park and Planning Commission, Department of Parks and Recreation). Jug Bay Wetlands Sanctuary is located on the eastern side of the river and Patuxent River Park is located on the western side.

3.2 HISTORICAL LAND USE AND CULTURAL RESOURCES

The information provided in this section, unless otherwise indicated, has been summarized from various web information sources, which are listed in the reference section of this site profile.

The Jug Bay component of the Reserve is a freshwater tidal marsh located in the middle waters of the Patuxent River bordered by Anne Arundel and Prince George's Counties. In addition to its richness in plant and animal diversity, Jug Bay holds many historical and cultural sites as well. A rich history has been buried in the soft organic sediments of the Patuxent River, and if uncovered one would find ancient Native American villages, water routes of European exploers, lost towns, shipwrecks, remnants of a golden crop, a hidden highway of commerce, and a lost path to freedom.

The origin of the name "Jug Bay," is an unsolved mystery. One popular theory among locals is that it came from a piece of Native American pottery, a remnant of a water jug, found along the river's edge. Not only have pottery pieces washed up on the banks of the Patuxent, but arrowheads, oyster and clam middens, and other archaeological evidence suggest that Native Americans were present from the Archaic Period (8000–1000 BCE) through the Woodland Period (1000 BCE–1600 CE). The English explorer, Captain John Smith, encountered 17 villages of Algonquian speaking Indians on a voyage in 1608. Of these 17, the tribes common to the Jug Bay area were the Acquintanack, the Mattapanient, the Assacomoco, and the River's namesake, as well as the most powerful, the Pawtuxent (Algonquian for "rapids."). These tribes were part of a confederation called the Piscataway Indian Nation. Recently, in 2009, archeologists at Jug Bay have uncovered the oldest Native American structures found in Maryland – wigwams that could date as far back as 500 CE.

During the Archaic period, the Piscataway were semi-nomadic and lived a life of hunting and gathering. As the climate warmed and glaciers retreated, the Chesapeake Bay was formed. With the Bay, came a new way of life, a life that revolved around the natural resources that the Bay offered. Settlement camps developed along the river. Wigwams were the earliest of shelters, used on a temporary basis during the warmer seasons. During the Woodland Period, however, the Piscataway became more sedentary and changed their temporary habitats to permanent villages made up of “Long Houses.” A long house was built by using young tree saplings and bending them into arches. The arches were then bound together and covered with woven marsh grass in the summer and furs in the winter. The long houses were located near the river, out of view from an enemy, yet close enough for the Indians to easily harvest the endless supply of fish and shellfish. The river was well stocked at this time, and the Piscataway took advantage of this bounty. Evidence of this can be seen in areas south of Jug Bay, where large oyster shell middens can be found. One midden measures 2000 feet long by 700 feet wide, and dates from 500 A.D. to 1400 A.D.

Not only did the waters of the Patuxent helped sustain these tribes, but the fertile and rich soil surrounding the river gave life to them as well. The Piscataway were farmers, and planted a variety of crops such as beans, corn, squash, tobacco, and sunflowers. They developed a method to clear the land for planting by burning and slashing. The cedar trees that were cut were used for their dugout canoes. The ability to make pattery enabled these tribes to store their seeds for planting, thus allowing them to expand their food supply. When the fishing season had passed, the Piscataway hunted ducks, geese, rabbits, black bear, and deer. In the winter, they would leave their summer camps and travel upriver to make tools and trap beaver. When they would come back in the summer, they would often move their settlements. Over time, the cleared fields became depleted of nutrients, and as a result the Indians would move, build new homes, and clear new fields.

Jug Bay and the Patuxent River provided the Piscataway with rich treasures. From the water’s depths it gave them an endless supply of food and rich soil, as well as providing them with a path for transportation, trade, and communication. The Piscataway Nation continued to establish homes along the Patuxent and lived peacefully until the 1600s, when Europeans arrived on their quiet shores. The first of these European explorers was a Spaniard, Vicente Gonzalez, who arrived in June 1588. It is believed that he, along with a small Spanish expedition, anchored for the night at the mouth of the Patuxent. Not much is known of this first expedition and it is often overshadowed by the famous Englishman, Captain John Smith, and his recorded exploration of the Chesapeake Bay and its tributaries. It was in 1608, during Smith’s second voyage, when he sailed up the Patuxent, and created a detailed map of the Bay while documenting a thorough description of the Native American tribes he encountered along the way. When describing the Patuxent, Smith says: “The fifth river is called Patuxent, of a less proportion than the rest but the channel is 16 fathoms deep in some places. Here are infinite skulls (schools) of diverse kinds of fish more than elsewhere."

By 1634, a flood of European settlers in pursuit of religious freedom swept along the east coast following in the footsteps of Smith. Some came as freeman, others as indentured servants. Those who landed at St. Clements Island established the first Maryland settlement, and its first capital, St. Mary’s City. Lord Baltimore, the English title given to George Calvert, was among this historic group of settlers. George Calvert was the first proprietor of the Province of Maryland, and his oldest son, Cecil, inherited the colony and the title after George passed away five weeks before the colony's new charter was sealed. George Calvert's second oldest son, Leonard, became the first colonial governor of Maryland.

In 1658, Philip, another one of George Calvert's sons, constructed a frontier outpost against Indian attacks. The outpost was located over an existing Pawtuxent settlement on a high bluff. The views were breathtaking and it was strategically located at the meeting of the Western Branch and the Patuxent River. At first the outpost was called Charles Town; however, in 1683 it became established as Mt. Calvert. By 1696, the heart of Jug Bay now had become the heart of the county. Mt. Calvert became the county seat for Prince George's County and by 1710, a jail, tavern, courthouse, and church had been built. At this time, the river was deep and ships frequented the river bringing goods from Europe. A riverside wharf was built to accommodate the visiting ships.

In 1721, the county seat was moved to Upper Marlboro and Mount Calvert was sold to a private buyer. Charles Town was no longer the frontier as colonists continued to spread along the Patuxent, bring with them invention and industry. At first it seemed that the profitable thing for the colonists to do would be to set up a thriving fur trade with the abundance of animal furs and beaver pelts. However, tobacco was in far greater demand in England. With the help from the Piscataway's horticultural experiences and the fertile rich soils of the river, the colonists turned their attention toward tobacco. By the mid 1630s, the farms along the Patuxent were England's most reliable suppliers of the high priced tobacco. The colonists became economically dependent on tobacco; in fact, anything bought or sold in the colony was priced in pounds of tobacco and until the 18th century, it was Maryland's number one cash crop.

Due to the value of tobacco farms were on the rise, and the cleared Indian lands were in high demand. European settlers slowly pushed the Native American from thier land and Piscataway began to slowly disappear. By 1672, most of the Native Americans of the Patuxent area were forced onto 700 acres of land set aside for them by Lord Baltimore, and by 1692, the last of the tribes left the reservation and joined other tribes near the Potomac River.

As Piscataway lands were plowed away, new colonial towns moved in. The once lush forests spotting the river bank, now gave way to rolling plantations. Thousands of acres of forests were stripped and wealthy colonists received 50 acres of land for each indentured servant they brought with them from England. Brick plantation mansions that now stood watch over the river, where native long house once stood. African American slaves where brought as a labor force. By 1700, the slave population around the Patuxent River represented 40% of the total population and was half of the areas workforce.

With the successful cultivation of tobacco, came the need to establish ports and towns in order to control the up and coming export and trade. In 1668, 1669, and 1671, through a series of declarations, Governor Charles Calvert, the son of Cecilius Calvert and Anne Arundel, created the first ports in the Maryland colony. Beginning in 1683 they passed a series of acts for the Advancement of Trade.

The Patuxent River became as valuable as the tobacco itself. From dugout canoes, to sailing vessels, the Piscataway and the settlers both realized the value of the river, not only for food and agriculture, but for commerce. For this reason, many plantations, like the Native American villages before them, were strategically located along the river. The colonists developed an easy method to pack, load, and ship the tobacco. First they packed the tobacco in large barrels called "hogsheads," which were then were rolled down to the river shore. From here they were loaded onto boats that would then transport them to larger ships anchored off shore. An effeicent system sent tobacco sailing down the river, through the Chesapeake, and enroute to trade with Europe and England. The tobacco industry dominated the Patuxent's economy for the next two centuries, with over sixty percent of Maryland's tobacco coming from the Patuxent valley by the late 1700s. The river was a path of good fortune for the colonists, but by 1775 this would all change as the Patuxent and America became embroiled in war.

The change occurred when England began to place embargos on colonial trade to Europe and the West Indies. In a political move, they also decided to support Native American's resistance to the colonial expansion. By 1775, colonial ties to the mother country had eroded; revolutionary sentiment began to spread like a wildfire, and it became clear that war was unavoidable. However, it was "The Second Revolutionary War," the War of 1812, which was significant to Jug Bay and the Patuxent River.

It was during the War of 1812 that a Royal Navy invasion force, under the command of Admiral Sir George Cockburn, successfully set up a blockade in the Chesapeake Bay. The deep draft British man-of-wars had difficulity in the shallow tributaries of the Chesapeake Bay. The Britisth were successful with their small, agile raiding parties which could enter the rivers with ease. In August 1813, an American, Commodore Joshua Barney, was determined to drive the British from the Bay. He successfully convinced the Secretary of the Navy, William Jones, to build a heavily-armed, shallow-draft fleet of row galleys (or barges) that could out-maneuver the British in the shallow waters. This fleet known as the "Chesapeake Flotilla" set sail on May 24, 1814 and was comprised of 26 ships, two borrowed gunboats, the sloop Scorpian, and 23 barges. A week later, he enguaged the British at the mouth of the Patuxent, but was forced to retreat up river. Barney and his men remained in the river for three months. By August the Brittish bagan to push upriver and Commodore Barney and his Chesapeake Bay Flotilla became trapped in the Jug Bay area. Barney was heavily outnumbered and decided to scuttle sixteen of his own ships, along with sixteen merchant vessels, in order to prevent the British advance. Not only did the blockade work, but it also prevented the American ships from being captured. Barney and his men would continue to fight in the Battle of Bladensburg and the Battle of Baltimore.

The Steamboat Era on the Patuxent began in 1817, when George Weems piloted his steamboat *Surprise* down the Chesapeake Bay for the first time. The Weems Steamboat line ran for close to ninety years until 1905, helping to sustain the tobacco industry as well as creating the new booming industry of passenger transport. Travel between the Patuxent and Baltimore brought vacationers. Resorts along the river were built, along with restaurants and hotels. In fact, from 1914 to 1939, there was even a floating theater that visited various Patuxent wharves. Roads and railroads did eventually come, and their arrival hastened the demise of the steamboats and consequently, the river towns.

The Chesapeake Beach Railroad was built in 1896 with over 27 miles of track laid down from Washington D.C. to the resort town of Chesapeake Beach. It was in operation from December 5, 1898 until April 15, 1935. Because the Patuxent River was navigable north of the railroad bed, a swing bridge was built over the river to accomidate steamboat traffic. By June 1935, the railroad was abandoned, and like the steamboat it lives on in stories that the river tells. Today hikers and scientists walk along the old railroad bed where it crosses the wetlands.

In the early 1900s, rail hunting became popular and drew many people into the Jug Bay area. It was a challenging activity, one that required a small skiff (called a rail boat), an experienced pusher, a fourteen foot long pole, and a skilled hunter. While rail hunting is still allowed today very few hunters pursue these game birds.

In 1929, the Great Depression hit farmers across the nation hard and Maryland was no exception. Boat builders and watermen continued to earn a good living and by the 1930s, the Civilian Conservation Corp and the New Deal helped to connect the area with other cities and town by the building of new roads and bridges.

World War II helped pull the country out of the Depression by creating more jobs and thus a more stable economy. The Patuxent River area joined in the fight in various ways. In the lower reaches of the river a shipyard was built for the production of transport boats. Also, the Navy built an amphibious base for the training of the D-Day invasion at Normandy. Beach landings were practiced on the sands of Calvert Cliffs. Across the Patuxent in St. Mary's County, the Navy purchased a farm at Cedar Point, at the mouth of the Patuxent River, and built the Patuxent River Naval Air Station (PAX NAS) for the purpose of consolidating the entire nation's air testing facilities. In fact, the Navy had tested the first U.S all jet powered plane at PAX NAS. In 1943, at the Air Base's commissioning ceremony, the Chief of the Navy's Bureau of Aeronautics called PAX NAS "the most needed station in the Navy."

From the Patuxent River's beginnings until now, there is common thread that ties all of its history and culture together. That common thread is the beauty and the bounty of its waters. From the miles of tranquil shoreline, to the dramatic high bluffs; from the variety of fish and animals to the variety of wetland plants and forest, the Patuxent River has attracted various cultures, and various ways of life, and all of them have enjoyed and used the resources offered by the river. Centuries of use, however, can become tragic as resources are abused, and over time the bounty will run out and the beauty will fade. Research and monitoring, education and outreach are important tools to creat awareness about the importance of these natural resources and the need to preserve them.

3.2.1 Archaeological Resources

During the past 30 years, archaeologists have been uncovering the riches of the archaeological history of the Patuxent River, particularly Jug Bay. This area holds the oldest human structures and artifacts found in Maryland including an 800-year old Native American dwelling called a wigwam (Roylance 2010) and 10,000 year old spear points (Furgurson 2009). Much of what is known about the Piscataway people that lived in this area at the time is from the artifacts such as pottery, tools, and ornaments that have been discovered in and around Jug Bay (Friebele et al. 2001). This all started when archaeologists and volunteers from the County's Lost Towns

Project dug a series of test pits on the bluff above Jug Bay in order to determine if there was any evidence of prehistoric settlement on the site.

As a result of these initial test digs, archaeologists found pottery sherds and arrow heads, which led to more digging within the area (Furgurson, 2009). Since then, many archeologically-important pieces have been found, some of which are so unusual that archeololgists do yet understand how they relate to other local collections. Archaeologists suggest that Jug Bay was a center for trade (Roylance, 2010). Also, the finding of piles of clam shells (including a freshwater clam now extinct in the local area) has led scientists and archaeologists to conclude that Jug Bay might have attracted people from other areas because of its vast water resources (Furgurson, 2009).

In addition to traditional archaeology, there are other methods of archaeology that archeologists use to interpret the past. Two methods that are being used in Jug Bay include the analysis of sediment cores and marine archaeology. For example, by analyzing a sediment core from the Patuxent River scientists determined a rapid accumulation of sediments that suggests a massive land clearing for agriculture between 1760 and 1860. As the land was cleared, erosion occurred at a more rapid rate and increased sedimentation of the rivers below the clearing (Friebele et al. 2001).

Underwater archaeology is particularly interesting and informative at Jug Bay. The Patuxent River and Jug Bay played a part in the war of 1812 where Joshua Barney led his crew in a confrontation of the British to try and stop their raids on the Chesapeake Bay (Lutz 2010). Barneys "Flotilla" was sunk near Wayson's Corner and parts of it used to be visible out of the water at low tide (Shomette 2009). Although no longer visible, research and excavation of the vessel that started in June of 1980 has revealed many artifacts such as medical instruments, a musket flint, water jugs, household items, etc.; all preserved intact because of the oxygen free conditions from being submerged (Friebele et al. 2001). This excavation has led to insights of what life was like on a 19th navel gunboat. Scientists were able to clearly see the architecture of the ship and were able to make conclusions about daily life aboard, including how seamen entered and exited the ship's holds (Friebele et al. 2001). While looking through all of the sunken remains, archaeologists and scientists believe they may have found Barney's flagship of the flotilla, the Scorpion (Lutz 2010). From 2010–2012 archaeologists with the State Highway Administration, in partnership with the U.S. Navy and the Maryland Historical Trust, will be conducting excavations just above Jug Bay to excavate and examine the wreck of this ship.

3.3 ENVIRONMENTAL SETTING

3.3.1 Geologic History

The Patuxent River is the largest river that lies completely within the state of Maryland. It drains roughly 900 square miles of land lying in portions of Howard, Anne Arundel, Montgomery, Prince George's, Calvert, Charles and St. Mary's counties (Tributaries Strategies Patuxent River Commission 2003). Jug Bay lies in the middle portion of the Patuxent River in the tidal freshwater zone within the western shore uplands region on the Coastal Plain (Figure 3.3.1). The

Coastal Plain is underlain by sediments dipping southeastwardly, which consist of sand, gravel, silt and clay and range in age from the Triassic to the Quaternary.

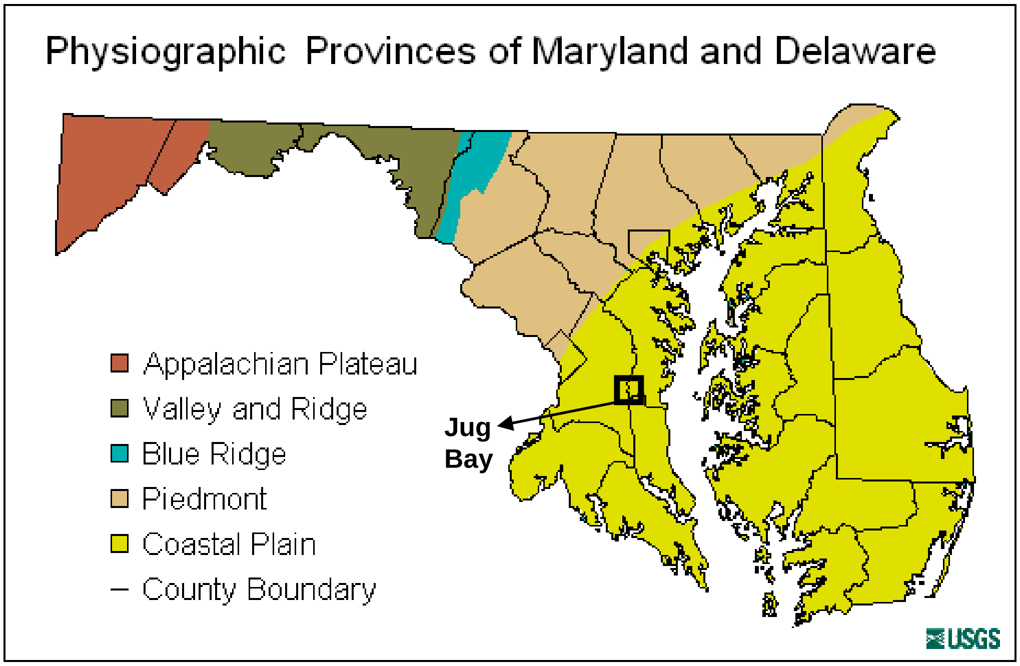


Figure 3.3.1 Location of Jug Bay in relation to Maryland physiographic provinces. Source: U.S. Geological Survey Physiographic Province Map of Maryland, Delaware, and the District of Columbia (2010).

Today's Chesapeake region drainage was formed during the most recent glacial event, the Wisconsin glaciation, during the Holocene epoch. The ice sheet retreated northward about 10,000 to 8,000 years ago and the glacial melt waters began to flood the Susquehanna River Valley and other ancestral Chesapeake Bay rivers. Between 5,000 and 3,000 years ago, rivers of the region began to turn into tidal estuaries which slowly formed the modern day Chesapeake Bay. Aquifers formed underneath the Coastal Plain due to rainwater and melted glacial waters trickling through the marine sediments, including sand, silt, gravel and clay (Grumet 2000).

The Atlantic Coastal Plain on the western shore of Maryland is composed of various layers of sediments from roughly 145.5 million years ago to present day (U.S. Geological Survey 2008). Below is a table (Table 3.3.1) briefly describing the geologic history, including a timeline and geologic events and the lithology of Atlantic Coastal Plain in Maryland (U.S.G.S 2010).

Table 3.3.1 Geologic history and lithology of the Atlantic coastal plain in Maryland. Source: U.S. Geological Survey (2010).

Period	Epoch	Geologic event	Lithology
Cretaceous 145.5 to 65.5 million years ago		**Magothy formation**	Sand; clay or mud; gravel
		Matawan formation	Sand; silt
		Monmouth formation	Sand; gravel
		Potomac group (Raritan and Patapsco formations, Arundel clay, and Patuxent formation)	Gravel; sand; silt/clay or mud
Tertiary 65.5 to 1.8 million years ago	**Paleocene** 65.5 to 58.8 million years ago	**Pumunkey group** (Aquia formation)	Sand
	Eocene 58.8 to 33.9 million years ago	**Pumunkey group** (Nanjemoy formation)	Sand; clay or mud
	Miocene 23.0 to 5.3 million years ago	**Chesapeake group** (Calvert formation)	Sand; clay or mud; sandstone
		Chesepeake group (Choptank formation)	Sand; silt; sandstone/coquina
		Chesepeake group (St. Mary's formation)	Clay or mud; sand
Quaternary 1.8 million years ago to present		**Upland deposits** (Eastern shore)	Gravel; sand; silt/clay or mud
		Upland deposits (Western shore)	Gravel; sand; silt/clay or mud
		Quaternary deposits undivided	Sand; gravel; silt/clay or mud/dune sand/beach sand
		Lowland deposits	Gravel; sand; silt/clay or mud

The predominant sediments surrounding Jug Bay are lowland deposits from the Quaternary period (Figure 3.3.2; darker yellow). The sediments just outside of the darker yellow are the Calvert formation from the Chesapeake group and the Nanjemoy formation from the Pumunkey group from the Tertiary period. Others surrounding the Jug Bay area include upland deposits (Western shore), the Monmouth formation, and sediments from the Potomac group.

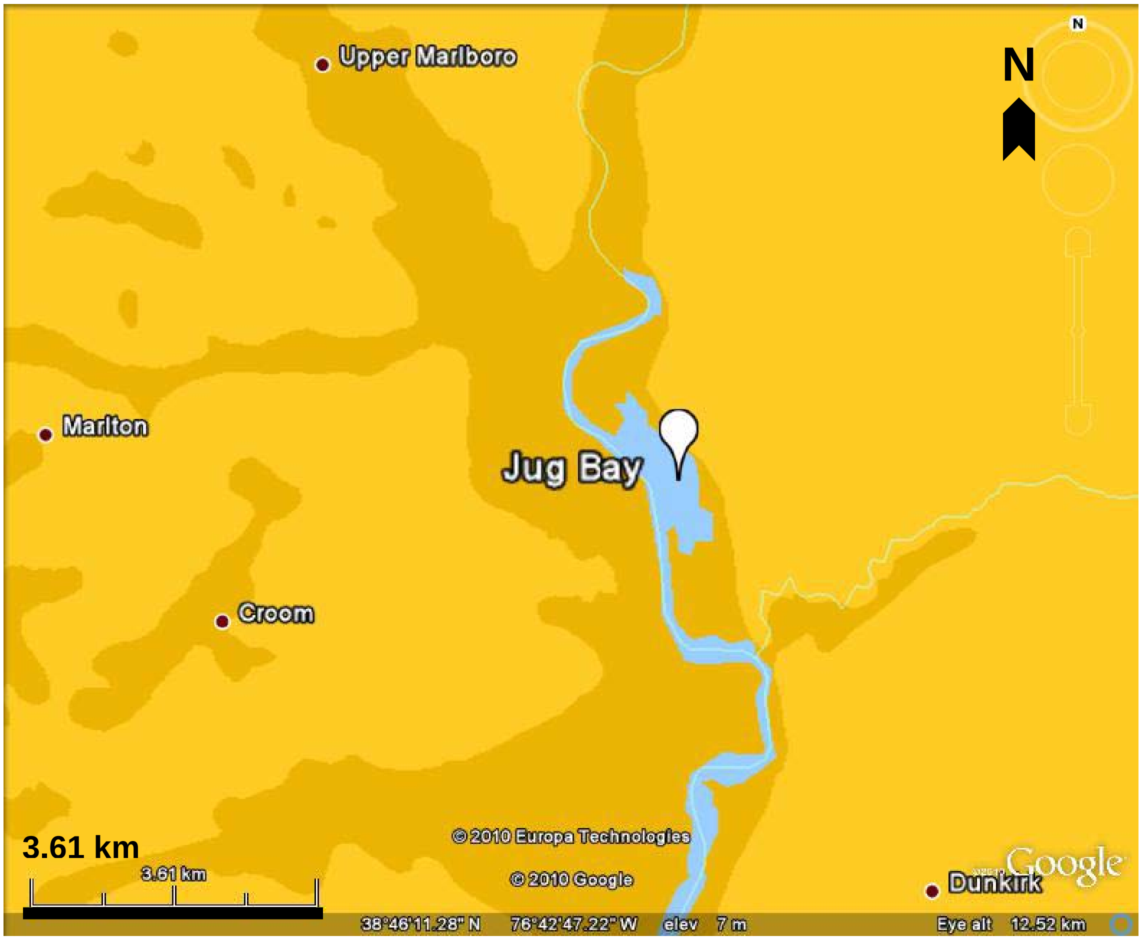


Figure 3.3.2 Geologic data layers of the Jug Bay area. Dark yellow indicates lowland deposits from the Quaternary period and ligher yellow indicates the Calvert formation from the Chesapeake group and the Nanjemoy formation from the Pumunkey group from the Tertiary period. Source: U.S. Geological Survey 2010, http://tin.er.usgs.gov/geology/state/state.php?state=MD).

3.3.2 Climate and Weather

The Jug Bay component is located within the humid subtropical climate zone, which is characterized by hot, humid summers and cool, mild winters (Ritter 2006, Encyclopedia Britannica Online 2010). Precipitation is typically evenly distributed throughout the year for this climate type (Ritter 2006).

Weather information presented in the following sections is based on data collected from weather stations, located in Upper Marlboro (38°52'N / 76°47'W) and within the Jug Bay component (38° 46' 50.52 N, 76° 42' 29.16 W; Figure 3.3.3). The Upper Marlboro station has been operating since 1956. Annual climatological summaries for this station were obtained through the NOAA National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html). The station at Jug Bay started operations in 2004. Data from this station are collected every 15 minutes and output as fifteen-minute, hourly, and daily averages, maximums, and minimums. All available data collected through this station can be viewed and downloaded from the Maryland Department of Natural resources eyesonthebay website (http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm) and/or the Centralized Data Management Office website: (http://cdmo.baruch.sc.edu/).

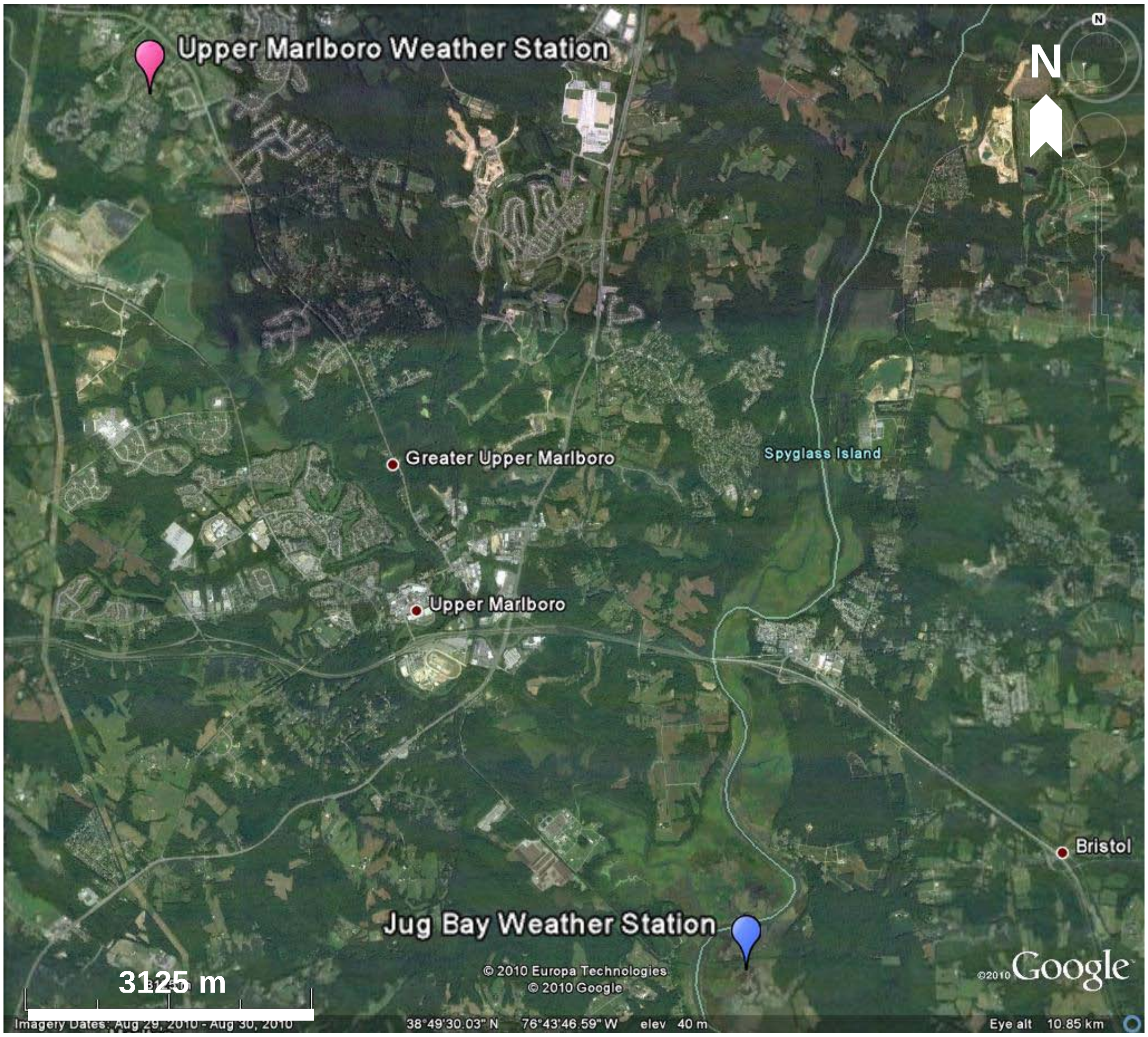


Figure 3.3.3 Location of the Upper Marlboro and Jug Bay weather stations.

3.3.2.1 Weather annual patterns

Relative humidity within the Jug Bay area is generally between 50.8 to 69.9% (Figure 3.3.4). November data was not collected at the Jug Bay meteorological station in 2004, therefore after omitting November, the relative humidity ranges between 62.2 to 69.9%. July through October has the highest average relative humidity ranging from 68.2 to 69.9% (Figure 3.3.4).

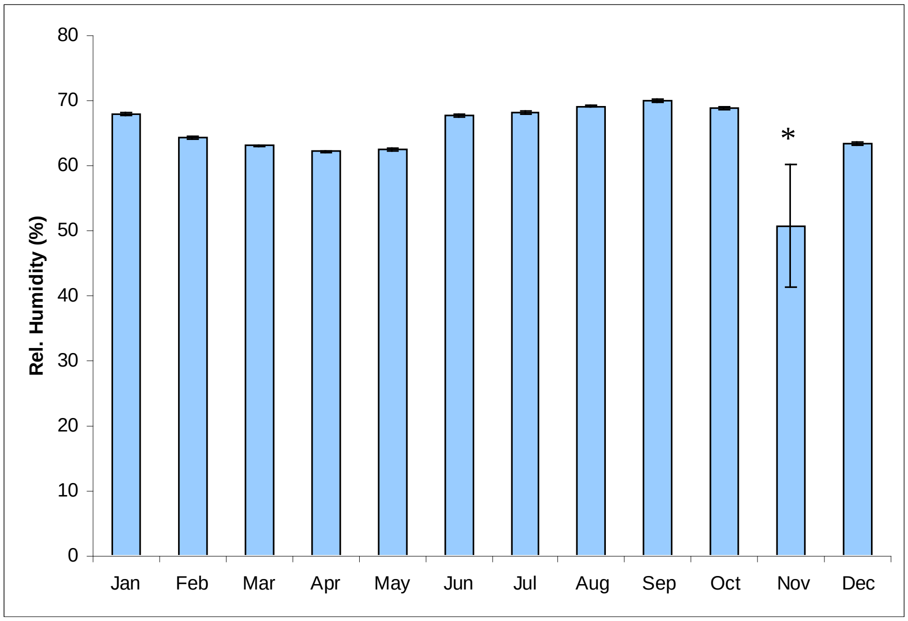
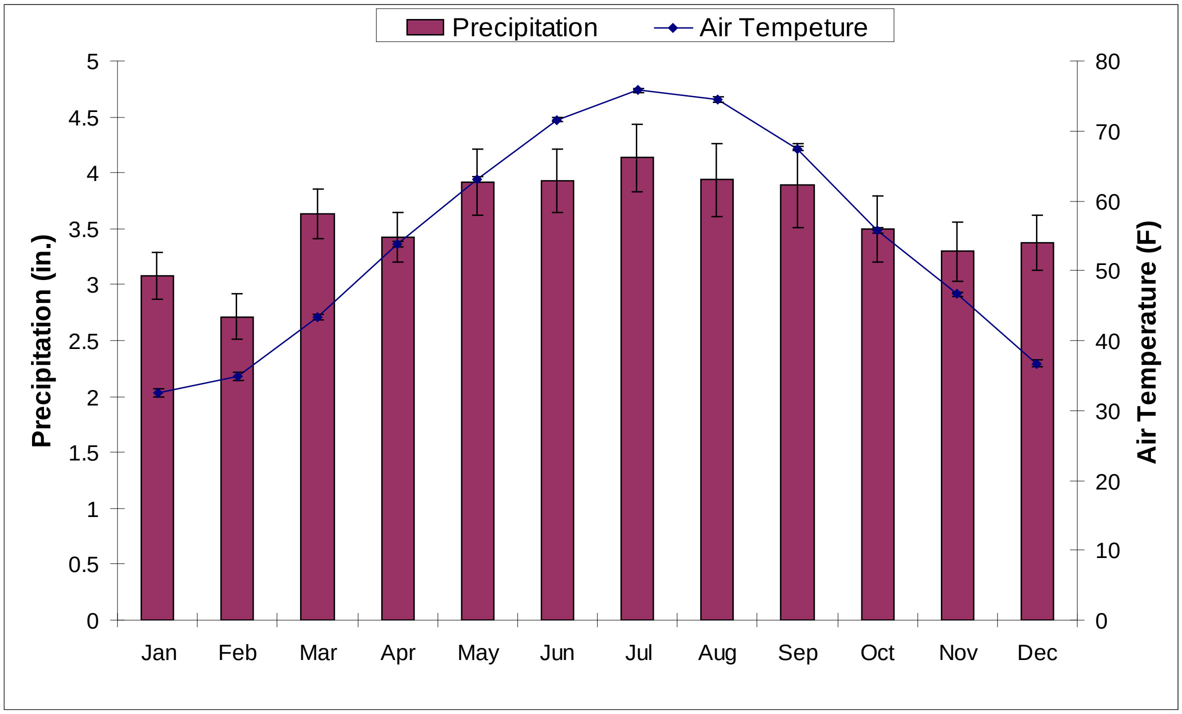


Figure 3.3.4 Monthly percent relative humidity averages for the period 2004-2009. Data source: Jug Bay weather station. November data (*) is for the period 2005-2009.

The average annual air temperature is roughly 12.6 °C (54.7 °F). The monthly average temperature ranged between 0.3 °C (32.6 ˚F) in January to 24.3°C (75.8 ˚F) in July. The annual precipitation can be quite variable but is usually fairly evenly distributed throughout the year (Figure 3.3.5). The monthly average precipitation ranges between 6.9 cm (2.72 in) to 10.5 cm (4.13 in). The average monthly precipitation is 9.1 cm (3.57 in) and the total annual average precipitation is 108.8 cm (42.82 in).

The precipitation pattern shows slightly lower precipitation during the colder months of the year (November-April) and higher precipitation during the warmer months (May-September; Figure 3.3.5). Thunderstorms often occur during the spring and summer, whereas during the winter there is occasional snowfall, which is much more common in the western mountain regions of Maryland.



Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precip. (in.)	3.08	2.72	3.63	3.42	3.92	3.93	4.13	3.94	3.89	3.50	3.30	3.38
Air Temp. (°F)	32.56	34.92	43.38	53.78	63.02	71.56	75.80	74.49	67.48	55.68	46.60	36.73

Figure 3.3.5 Monthly average air temperature (°F) and precipitation (in.) from 1956 to 2009. Data source: Upper Marlboro weather station (NOAA National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html).

Year-to-year weather patterns

The average annual air temperature from 1956 to 2009 was roughly 54.6 °F (12.5 °C). Temperatures range from 52.8 to 57.8 °F (11.6 to 14.3 °C). The year-to-year average air temperature is variable; however, there seems to be an overall increasing trend in temperature (Figure 3.3.6).

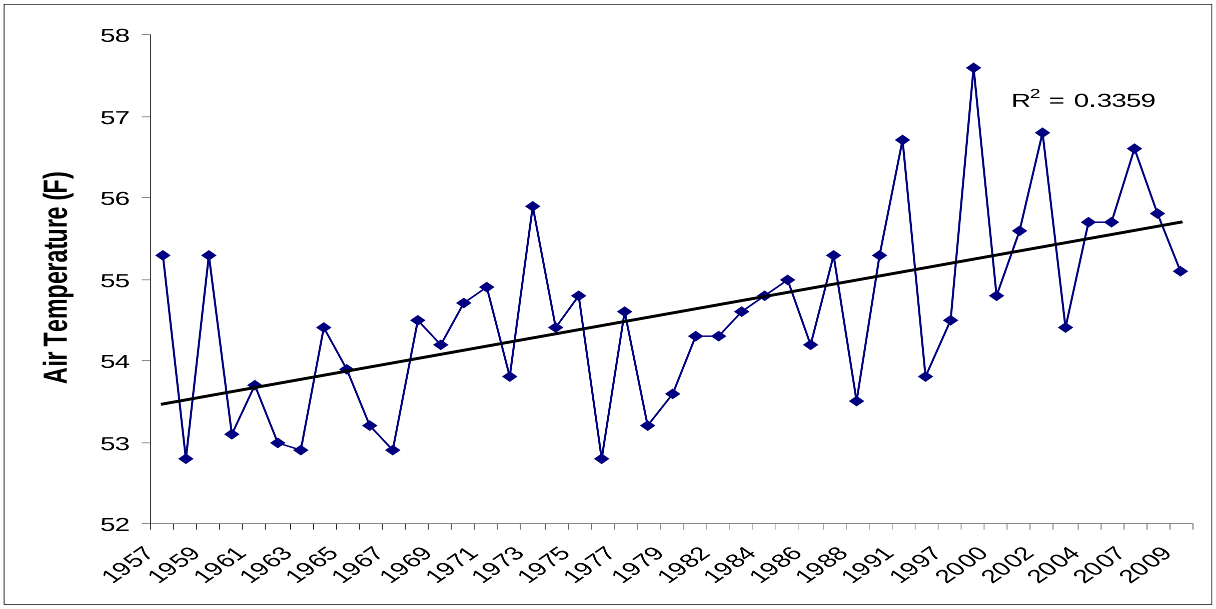


Figure 3.3.6 Yearly average air temperatures (°F) for the period 1956-2009. Data source: Upper Marlboro weather station (NOAA National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html).

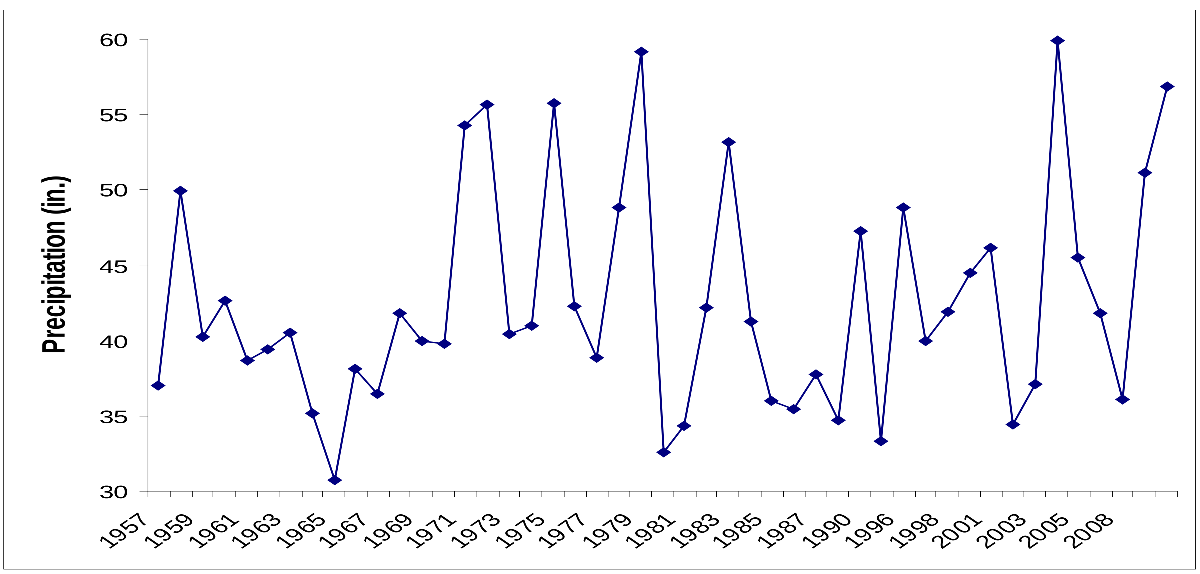


Figure 3.3.7 Yearly total precipitation (in.) for the period 1956-2009. Data source: Upper Marlboro weather station (NOAA National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html).

3.3.3 Estuarine Geomorphology, Soils, and Sedimentary Processes

Tidal freshwater wetlands are areas of hydrophytic vegetation with underlying sedimentary deposits in an intertidal zone. They occur upstream of more saline tidal waters and downstream of nontidal areas. The physical structure is a result of the interaction of regional topography and the geology of the area, combined with sedimentary processes that result from both natural and anthropomorphic processes. Jug Bay is situated on the coastal plain of Maryland, adjacent to the fall line where low topographic relief and large volumes of water flowing into the system create expansive areas where the soils remain inundated for periods of time ranging from a few hours per day to several months of the year, depending on their position within the system.

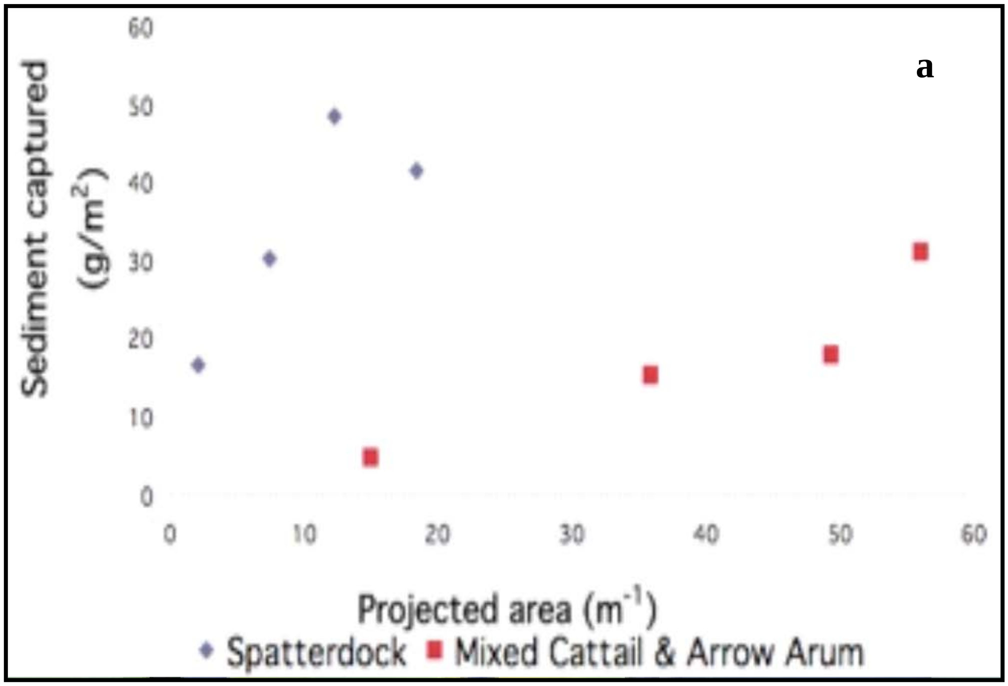
The natural erosion of sediments from upstream sources is a process of breaking down parent rock material and transporting it downstream. The characteristics of the rock and the habitat through which the eroded rock must travel influence the sediment that reaches a downstream sink. Jug Bay is in the Lower Patuxent Valley Area, part of the Coastal Plain Province. As part of the coastal plain, the underlying substrate is made up of sediments transported from upland areas. According to the Maryland Geological Survey's Geologic Map of Maryland (1968), Jug Bay has underlying lowland deposits of gravel, sand, silt and clay. The texture of the substrate is medium- to coarse-grained sand and gravel with cobbles and boulders. It commonly contains reworked Eocene glauconite. The sediments are composed of varicolored silts and clays with brown to dark gray lignitic silty clay. It contains estuarine to marine fossils in some areas and the thickness is up to 150 feet (46 m). Most sediment that has been deposited in the last 8,000 years in the Chesapeake Bay remains unconsolidated, and those deposited in the last few hundred years retain more than 50% water in pore spaces (Langland et al. 2003), creating a substrate that is soft and prone to subsidence. Sediment also contains some volume of toxic substances that can impair populations of living organisms.

The marsh is shaped by physical and biotic forces including the sediment load delivered to the marsh, the hydrology of the river, shallow subsidence, deep subsidence and uplift, the vegetation of the marsh, weather events, changes in sea level, and anthropomorphic changes upstream. An increase in sediment load generally leads to marsh building in a tidal estuary (Khan and Brush 1994). Changes in river hydrology affect the volume of water entering the marsh, thereby influencing the patterns of sediment deposition and vegetation. Accretion and subsidence are opposing forces in marsh dynamics. Accretion is the accumulation of sediment contributing to surface elevation increase. Shallow subsidence can be caused by compaction and/or decomposition of organic matter in the soil. Deep subsidence and uplift are geologic processes of crustal sinking and rising. Vegetation contributes to accretion in two ways: it slows the water, to which allow sediment deposition and deters sediment resuspension (Lopez et al. 1998), and through the growth and eventual decomposition of wetland plants which adds below-ground biomass, organic matter and detritus to the system. Weather events such as hurricanes and large rainstorms temporarily alter the hydrology and can move sediment deposits downstream, remove marsh vegetation, and deposit new sediments. Rising sea level could potentially flood the marshes, coverting this habitat to deep open water and unvegetated tidal flats. Taking into consideration geologic subsidence and global warming, Larsen (1998) estimates the Chesapeake Bay relative sea level rise at 2.7 to 4.5 mm (0.1 to 0.2 inches) yr^{-1}. This would in increase of 27 to 45 cm (10.6 to 17.7 inches) of the next 100 years. Anthropomorphic disturbances also have the potential to change the hydrology of a river system. The interaction of all these forces creates a dynamic environment subject to change over various time scales.

European settlement and land use caused significantly higher loads of suspended sediment to be delivered to the tributaries of the Chesapeake Bay, including the Patuxent River, creating changes in the landscape. Before the 17th century, there is evidence that Jug Bay was a deep water habitat thickly populated with submerged aquatic vegetation (Pasternack and Brush 2001). Khan and Brush (1994) found that the Jug Bay marsh formed in response to land clearance by European colonist. During the 18th and 19th centuries, approximately 70-80% of the forest in the Chesapeake Bay drainage basin was cleared for agriculture and timber production. Soil erosion rates severely increased compared to pre-colonization levels, creating a large sediment load from the uplands into the river tributaries of the Chesapeake Bay. The deposition of sediments transformed the open water habitat into a marsh/wetland system. Sediments from the early colonization period are still present in marsh and floodplain zones: Jug Bay has legacy sediments dating back to the 17th century (Khan and Brush 1994). Erosion rates have not returned to pre-colonization rates, probably due to urbanization and the remobilization of previously eroded sediments (Langland et al. 2003). In some areas, marsh building continues to the present day, with higher elevations of the marsh containing recently deposited sediments: using pollen and seed analysis from sediment cores, Khan and Brush (1994) found that the high marsh formed within the last 100 years, probably due to high sedimentation rates from agriculturally-derived sediment runoff. They also found higher amounts of nutrients and pollutants in the high marsh than in the low marsh.

The interactions between vegetation and sedimentary processes are complex. Sediment is delivered from upstream sources into the intertidal area. As the current reverses during high tide, suspended sediments are deposited. Lopez et al. (1998) found that the presence of stems of submerged and emergent vegetation decreased the bottom current velocity contributing to sedimentation by increasing particle capture and reducing particle resuspension. The submerged plants help to capture the sediments, but the suspended sediment load creates turbid conditions which inhibit submerged plant growth. In open water areas of the marsh, deposition builds the underlying sediments, creating less optimal conditions for recruitment of submerged aquatic vegetation. Once sufficient sediment has been accumulated, the subtidal areas can become intertidal. Intertidal areas are quickly colonized by low marsh vegetation. Pasternack and Brush (2001) found that plant cover in the intertidal areas positively impacts marsh building; the emergent vegetation facilitates the capture of additional sediment.

Several studies have shown that vegetation type influences patterns of sediment deposition and erosion. Pasternack and Brush (2001) studied the effect of different plant communities on sedimentation rates and found that low marsh habitat dominated by *Nuphar lutea* (spatterdock) was the most efficient at capturing sediment. A study conducted at Jug Bay support these findings; communities of *N. lutea* showed higher sediment capture per plant projected area (which takes into account leaf surface area, density and volume; Figure 3.3.8a) and also overall higher rates of accretion than other parts of the marsh at higher elevations (Figure 3.3.8b). Not considering sediment compaction or subsidence, it is predicted that the *N. lutea* zone overall is likely to keep pace with sea level rise rates if sediment loads remain constant (Cummings and Harris 2008).



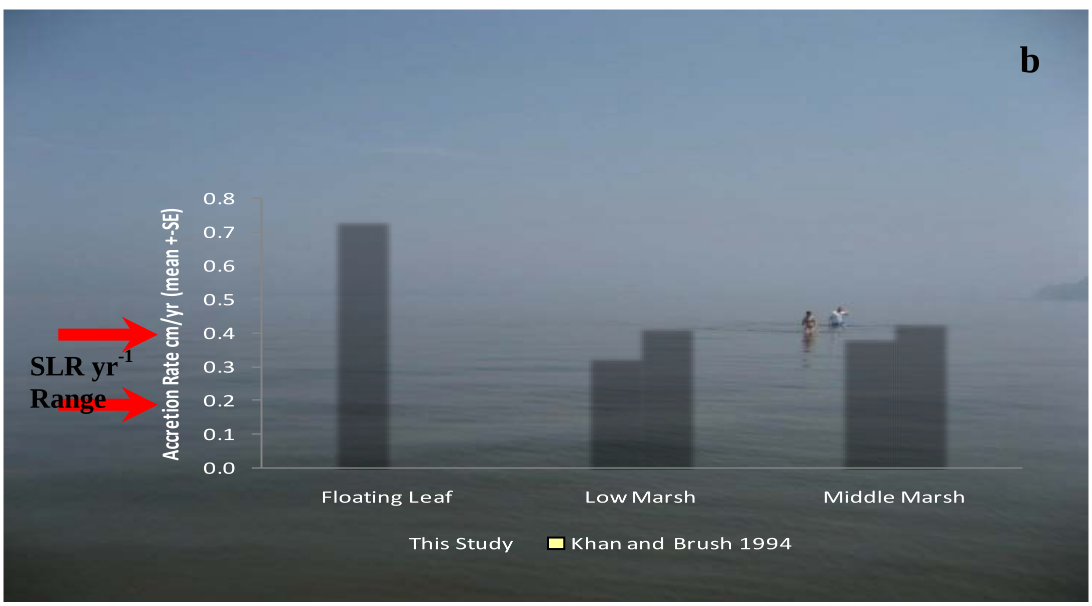


Figure 3.3.8 (a) Sediment capture per projected area by plant community. (b) Accretion rate by marsh zone, where floating leaf corresponds to a *Nuphar lutea* dominated community. Source: Cummings and Harris (2008).

Rooth and Stevenson (2000) compared sedimentation and elevation change in marshes containing native *Spartina* spp. grasses with marshes containing the invasive *Phragmites australis*. The *P. australis* communities had both higher sediment deposition rates as well as higher rates of positive elevation change. In a related study, Rooth et al. (2003) found significantly higher rates of sediment accretion in *P. australis* communities, as well as increases in elevation, as compared to adjacent areas occupied by *Typha* spp. and *Panicum virgatum.* The authors suggest that resource managers can use this information as they plan strategies for combating sea level rise in critical habitats.

Pasternak and Brush (2001) and Darke et al. (2003) found that in addition to habitat type, the time of the year affected sedimentation and erosion in freshwater tidal marshes. Most sediment accretion occurs in spring and summer during the growing season when there is a high density of plant stems. During the winter months, the stems of many low marsh plants (for example, *Nuphar lutea*) senesce and decompose, creating mudflats that are devoid of vegetation and are subject to erosion. Preliminary results of sedimentation studies at Jug Bay show a similar pattern where greatest surface elevation change in the north and south Glebe marsh occurs during the growing season (Figure 3.3.9; Delgado et al. 2011, unpublished data). The Glebe marsh was bisected (into the north and south Glebe marshes) in 1895 by the construction of the railroad bed (now abandoned), which has modified the hydrology and sedimentation dynamics in this marsh over the intervening years.

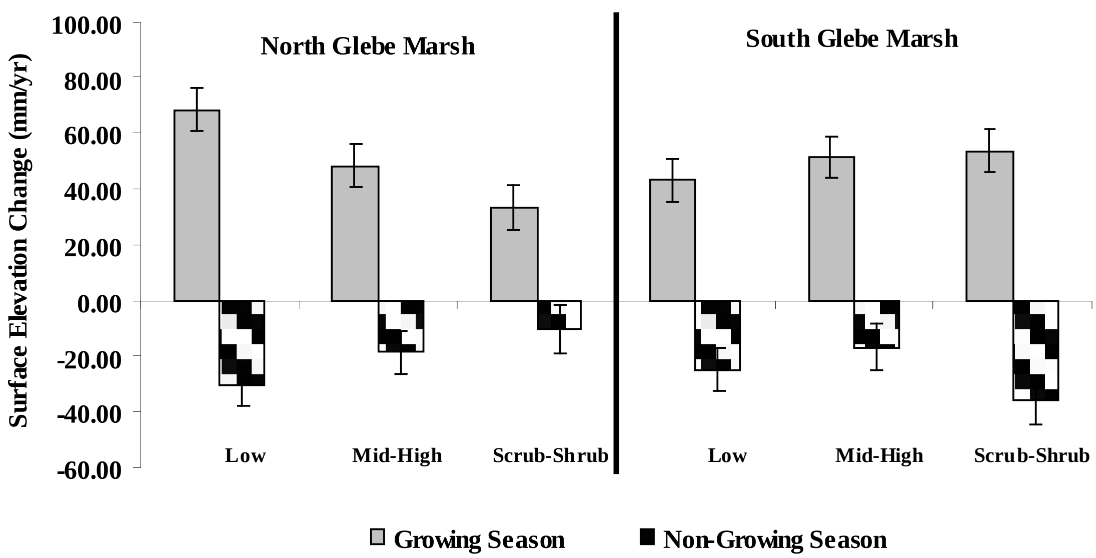


Figure 3.3.9 Seasonal effects of surface elevation change at the north and south Glebe marsh, Jug Bay. Source: Delgado et al. (2011, unpublished data).

This same study at the Jug Bay Glebe marsh has shown an average marsh surface elevation change of 0.0 $\pm$ 1.6 mm yr^{-1} in north Glebe and 5.8 $\pm$ 1.6 mm yr^{-1} in south Glebe. These rates indicate that while the south Glebe marsh is able to keep up with projected relative sea level rise for the Chesapeake Bay (2.7 to 4.5 mm yr^{-1}, Larsen 1998), the north Glebe marsh is not.

The study conducted by Delgado et al. (2011, unpublished data) showed that even though sediment and organic matter accumulation was always positive at all sampling sites throughout the south and north Glebe marshes (26 ± 7 mm yr^{-1} and 23 ± 8 mm yr^{-1} average vertical accretion for south and north Glebe marshes, respectively), this accumulation did not translate into actual marsh elevation change. This could be the result of various processes including decomposition of deposited organic matter, compaction, and/or subsidence. However, vertical accretion data did show an overall significantly higher sediment accumulation within the low marsh zone compared with the mid-high and scrub-shrub zones (44.9 ± 5.0 mm yr^{-1} vs. 17.1 ± 5.0 mm yr^{-1} and 11.2 ± 5.0 mm yr^{-1}, respectively; Figure 3.3.10).

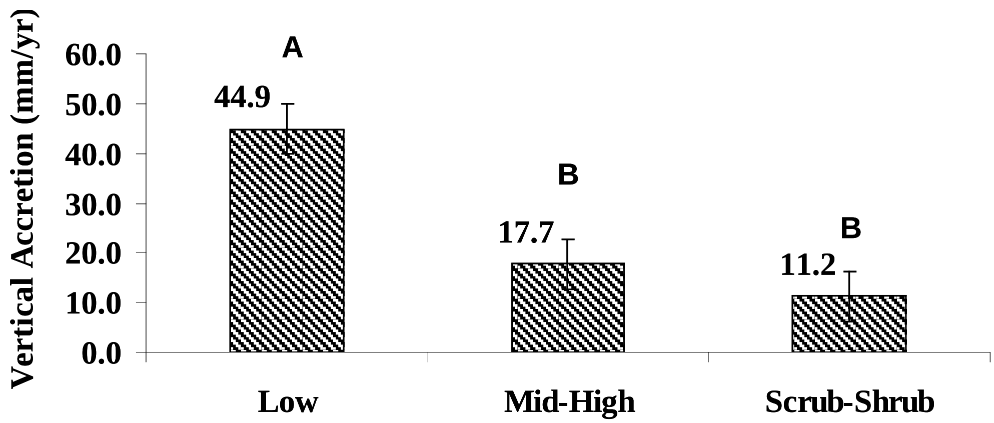


Figure 3.3.10 Rates of vertical accretion at the north and south Glebe marsh, Jug Bay, Patuxent River. Different letters indicate a significant difference between low marsh and mid-high marsh zones (p=0.0083) and between low marsh and scrub-shrub zones (p=0.0013). Source: Delgado et al. (2011, unpublished data).

As the construction of the railroad bed has altered the hydrology and sedimentation dynamics between the north and south Glebe marsh since its construction in 1895, other current anthropomorphic disturbances continue to threaten the physical structure of the Jug Bay wetlands. The drainage basin of the Patuxent contains urban and suburban areas that are expanding, and the construction of additional impervious surfaces may further alter the hydrology of the river and associated streams.

3.3.4 Hydrology

In terms of hydrology, the ecology of a tidal freshwater wetland (e.g., species distribution, composition, plant density, etc.) is mainly governed by its hydrological regime which drives water level changes and the exchange of materials as a function of daily, monthly, and seasonal processes including river discharge, tides, winds, as well as unpredictable events such as storms and hurricanes.

The hydrology of Jug Bay is mainly regulated by the Patuxent River estuary and its tributaries which are locally linked to the input and exchange of freshwater and sediments to the system; and by the Chesapeake Bay which brings the influence of the tides and the transport of salt water upstream. The occurrence of storms and the influence of winds on water levels are other important factors which modify the hydrology of the Jug Bay wetlands system.

3.3.4.1. River discharge

The tidal freshwater system at Jug Bay is mainly characterized by the input and exchange of freshwater, sediments, and nutrients from the Patuxent River and its network of streams and creeks from adjacent watersheds. Two-run Branch, Galloway Creek, and Pindell Branch, which drain the component on the east, and Mattaponi Creek, Black Walnut Creek, and the Western Branch which drain the the western component are the major streams that flow into the Patuxent River and the Jug Bay component (Figure 3.1.2).

As part of a summer project, a research intern with the Jug Bay Wetlands Sanctuary developed a characterization study for some of the creeks located on the east bank of the Jug Bay component. Results of this characterization are included in Table 3.3.2.

Table 3.3.2 Characterization of creeks found along the eastern bank of the CBNERR-MD Jug Bay component. Source: Moshogianis (2009, unpublished data).

Stream	Watershed Size (ha)	Stream Length (km)	Discharge ($m^3\ sec^{-1}$)	% Impervious Surface*
Galloway Creek	566 (1,396 ac)	2.1	2.4	22 (126 ha)
Two-run Branch	356 (880 ac)	1.4	1.8	24 (82 ha)
Pindell Branch	208 (509 ac)	0.9	0.9	10 (21 ha)

*Impervious surface = Residential, commercial buildings, and roads.

The United States Geological Survey (USGS) gauge stations located on the Patuxent River near Bowie, Maryland and in Western Branch have been in operation since 1977 and 1985, respectively. The station near Bowie is about 32 km (20 miles) north of Jug Bay, while the Western Branch station is 4.8 km (3 miles) north of Jug Bay in Upper Marlboro, above the head of tide on Western Branch.

Intra and interannual variability of the Patuxent River discharge is credited to the local precipitation patterns as well as climatic events (Figure 3.3.11 and 3.3.12). The annual discharge cycle shows high flow in spring associated with snowmelt and precipitation followed by low flow during the summer and increase flow again in late fall and winter (Figure 3.3.11). The larger discharge of the Patuxent River gauge seems to be correlated with its larger watershed compared with its tributary Western Branch.

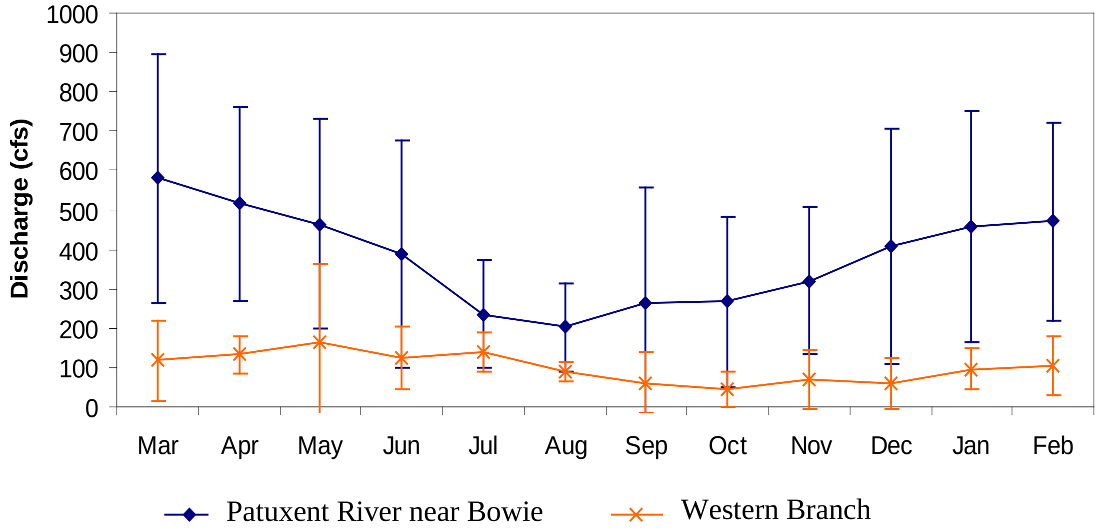


Figure 3.3.11 Mean monthly discharge (cfs = cubic feet per second) of the Patuxent River near Bowie (1978-2009) and Western Branch (1986-2009). Data source: U.S. Geological Survey Water Resources (http://water.usgs.gov/).

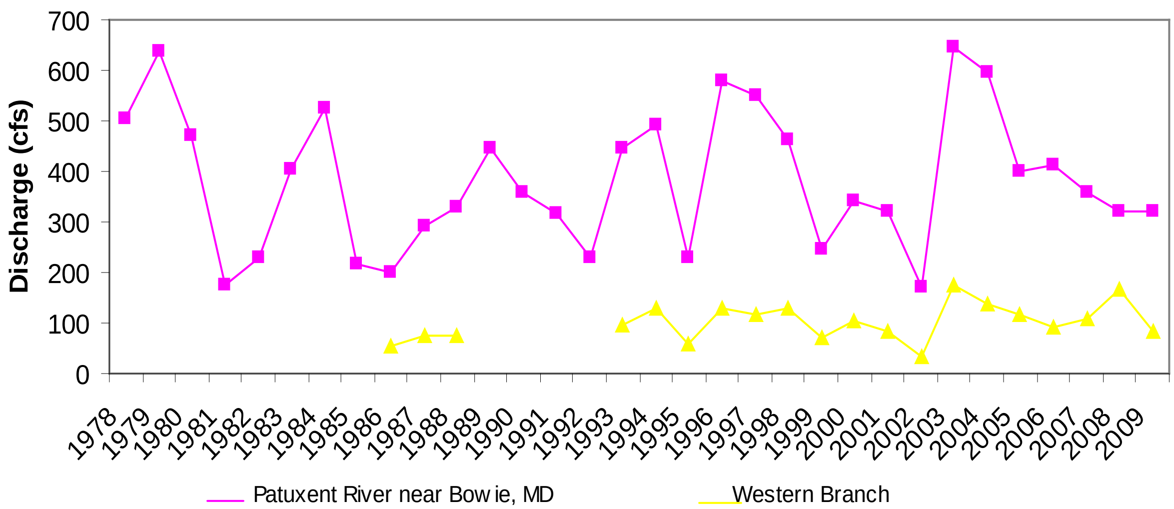


Figure 3.3.12 Mean annual discharge (cfs = cubic feet per second) of the Patuxent River near Bowie (1978-2009) and Western Branch (1986-2009). Data source: U.S. Geological Survey Water Resources (http://water.usgs.gov/).

3.3.4.2. Tides

The Jug Bay tidal freshwater marsh system experiences two high tides and two low tides about every 25 hours, with a tidal amplitude of about 2.5 feet (0.8 m). When the tide rises there is a net input of water and other materials into the wetland system, and when the tide falls, there is a net export from the system. The flushing rate often responds to river discharge, particularly during the spring season, but wind may also have an important influence bringing water in or out of the marsh. Depending on marsh elevation and the position with respect to the river channels and large marsh channels, Jug Bay Wetlands may experience daily or seasonal flooding by the tides. Also, because the degree of flooding is related to the marsh elevation, a difference in frequency and duration of flooding could be observed between low and high marsh zones.

3.3.4.3. Wind, Storms, and Hurricanes

Winds, storms, and hurricanes may also have an important temporary effect in the hydrology of Jug Bay wetlands, particularly by rapidly changing the water levels in shallow areas. The Patuxent River flows through a relatively narrow, flat floodplain in the Jug Bay region so the water level is susceptible to increased water volume from storms and to high winds. Winds blowing from the south (downriver) can push in estuarine waters upriver which can raise the water levels far above a normal high tide. In contrast, winds from the north or northwest (upriver) can blow the water out of Jug Bay causing bare mud to be exposed for many hours.

Hurricane Agnes in 1972 and Tropical Storm Isabel in 2003 are considered to be the most destructive tropical storm events in the Chesapeake Bay region since 1933. Storm surges were recorded above 8 feet (2.5 m) throughout coastal Maryland, Washington D.C., and Virginia (NOAA National Hurricane Center). Every year, a variable number of storms pass through this area and they play an important role in the estuarine ecosystem as they move water, sediments, and other materials in and out of the tidal wetlands. The ultimate impact of these irregular and unpredictable events to the Jug Bay system depends on their frequency and intensity, which may increase as a result of predicted climate change.

3.3.4.4. Groundwater

Drinking water for many residents in the northern or upper Patuxent River watershed (for example, Howard, Montgomery and Prince George's counties) comes from dammed reservoirs that were created in the upper regions of the Patuxent River. Municipal or private wells drawing on groundwater provides drinking water for residents in the southern or lower part of the watershed. There are concerns that pollution could contaminate reservoirs, streams, and groundwater in the Patuxent River watershed, which could lead to increased expenses as the establishment of new systems will be needed to make water potable. In addition, the increase of impervious surfaces and withdrawels within the watershed could cause the water table to decline and therefore the availability of drinking water for human consumption in the future (Patuxent Riverkeeper 2007).

Phemister (2004) studied the importance of the source of groundwater for determining nutrient and sediment removal in Jug Bay tidal marshes. Evidence showed that nutrient and sediment deposition is greater in marshes where the main source of incoming water is tidal flooding. In these areas, the soils absorb the nutrients and sediments as the water filters through the marsh vegetation. However, if the main source of marsh groundwater is an upland aquifer, the tidal water will be less likely to infiltrate the already-saturated soil, leaving a greater amount of nutrients in the water as it flows back to the stream channel.

3.3.5 Land and water use history

3.3.5.1 Historical changes

The Native American tribes of the Patuxent River lived off the land and river for thousands of years prior the first European landing. However, sediment records only show the major influence of land-use on the environment after the European settlement in the 17th century (Brush and Davis 1984). Significant ecological impacts are observed in the 18th century when massive land clearing and new farming techniques were being implemented. During this time, tobacco farming spread and created a residential boom of houses and plantations along the river instead of a typical urban city center. Thousands of acres of forest were cleared for tobacco and corn farms. Building directly on the river allowed planters to roll their product downhill straight onto an oceangoing trade ship. The trade village of Charles Town was established in 1683 at the site currently known as Mount Calvert. Tobacco farming however was so profitable that land continued to be cleared without regulation. The trade ports became so clogged with sediment and debris that by 1759 the town raised money to have the river dredged. The small ports of Jug Bay were no longer commercially viable by the end of the 1700s. Over 75,000 people lived in Southern Maryland by this time.

Studies in Jug Bay's freshwater marshes show sediment rates to be 0.05-0.08 cm (0.019 – 0.032 inches) yr^{-1} before European settlement. In the mid-1800s, the peak of land clearance, the sediment rate increased the times to an average of 0.50 cm (0.19 inches) yr^{-1} (Khan and Brush 1994). Waterways became narrower and shallower as the river filled in with excess sediment. The low marsh became high marsh and open water was converted into low marsh (Khan and Brush 1994).

The invention of the steamboat, which drew only six feet of water, allowed trade to again prosper along the Patuxent. The steamboat became the only long-distance transportation option during the 1800s for freight and eventually passengers. Even steamboat transportation eventually ended because ports could no longer be reached due to the high rates of sedimentation. At Pig Point just above Western Branch, the Army Corps of Engineers dredged a channel ten foot deep and 450 feet long in 1888 and again in 1904 to keep this small port open at the head of the steamboat navigation on the Patuxent.

The Chesapeake Beach Railroad was completed in 1896 and became the preferred travel method for the area. The line was abandoned 35 years after its first run in 1900. The railroad bed through the marsh still exists and the pivot turnstile bridge support is still visible in the river where the train crossed Jug Bay. The railroad beds that extend into the marsh of both shores have trapped sediment and allowed the increase in sediment build up. The end of the railroad also coincides with the fading interest in sora rail hunting, partly due to the increased siltation that made it difficult for even rail boats to navigate the marsh.

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3.3.5.2 Recent land use change and trends

The region surrounding Jug Bay has continued to grow. The population in the Patuxent watershed increased from 86,000 people in 1950 to 500,000 people in the year 2000. As a result, the annual load of sediment accumulating in the Patuxent River has also increased from 160,000 tons in 1950 to 710,000 tons in 1980 (Friebele et al. 2001). A sedimentation peak is particularly evident in the mid-1960s through the mid-1970s and again in the early 1980s when urbanization was at its highest rate (Khan and Brush 1994).

The increased population has also resulted in increased waste water effluent. By 1989, 40 million gallons of effluent per day was released into the river by wastewater treatment plants (Friebele et al. 2001). The Western Branch Wastewater Treatment Plant, located on the Western Branch tributary of Jug Bay, is the Patuxent River's largest single source of treated effluent.

The decreasing health of the Patuxent River, specifically with increased sediment, prompted the Patuxent River Watershed Act in 1961 with the goal of restoring the river to the 1950 water quality levels. Maryland signed the Chesapeake Bay Agreement in 1987 promising to reduce nutrient pollution to the Bay by 40% by the year 2000. The successful modifications to the Western Branch Wastewater Treatment Plant are the reason the Patuxent River leads the Bay's tributaries for nitrogen reduction. Phosphorus levels have also declined since the state banned phosphorus in detergents in 1985.

Another source of environmental enhancement to the mid-Patuxent River was the establishment of the county parks surrounding the Jug Bay area. In 1974, 72 hectares (178 acres) of land was purchased and protected, which would become the Jug Bay Wetlands Sanctuary in 1985. Today the sanctuary incudes about 647 hectares (1,600 acres) and is the largest Anne Arundel County Park. It is dedicated to ecological research, education, and habitat protection. Patuxent River Park currently manages over 2,832 hectares (7,000 acres) along the western shore of the Patuxent River – 230 hectares (596 acres) of these (Jug Bay Natural Area and Black Walnut Creek Area) are included in the Reserve. The natural area is managed by the Maryland-National Capital Park and Planning Commission (M-NCPPC) for recreation, research, and environmental education. M-NCPPC began acquiring land after the Patuxent River was declared a valuable resource worth protecting in 1961 by the state of Maryland.

The establishment of the county parks has provided a protective buffer along both sides of the river, diminishing the potential for development in these areas. An analysis of land use within the boundaries of the Jug Bay component shows forest, wetlands, and open water as the main components with some reduced areas including cropland and pastures (Figure 3.3.13).

At a smaller scale, a land use characterization analysis conducted for the subwatersheds of Galloway Creek, Two-run Branch, and Pindell Branch indicates forest as the main land cover for the three streams; other dominant categories include wetlands, residential, and raw crops (Table 3.3.3).

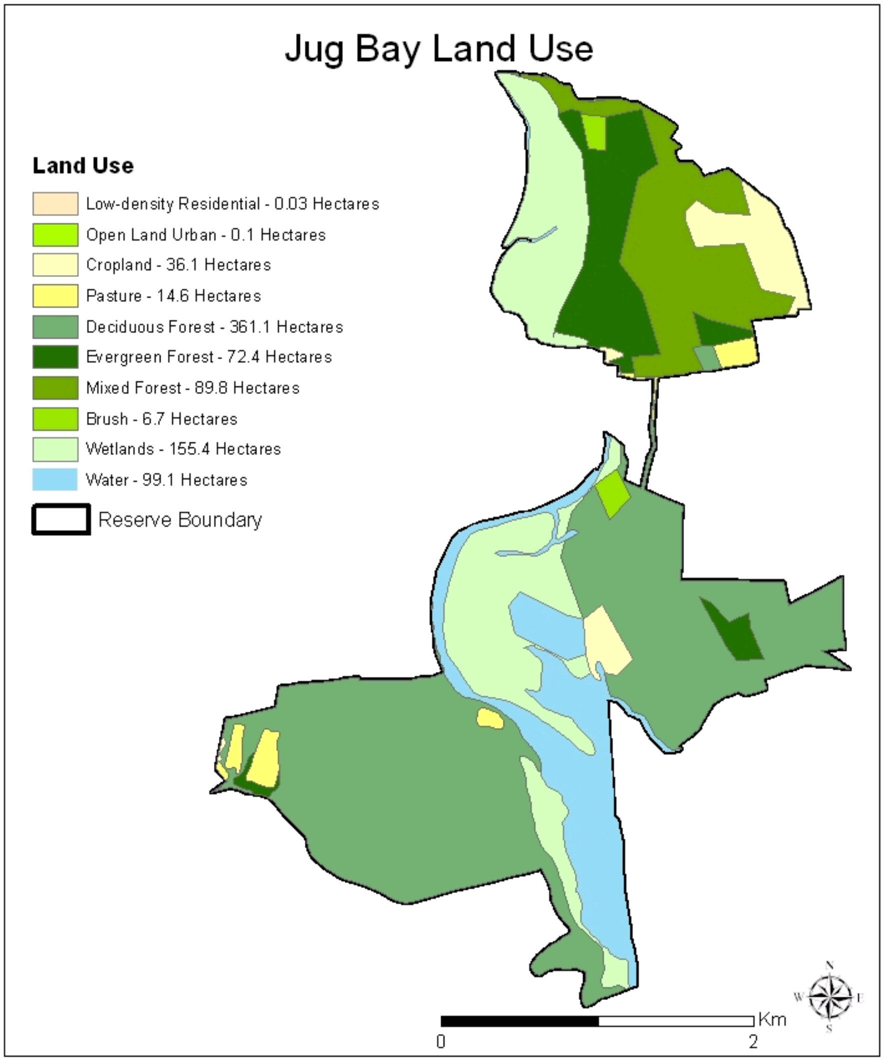


Figure 3.3.13 Land use classification within the boundaries of the CBNERR-MD Jug Bay component.

Table 3.3.3 Land use sub-watershed characterization of creeks found along the eastern bank of the CBNERR-MD Jug Bay component. Source: Moshogianis (2009, unpublished data).

Land Use	**Acreage (Percent in parenthesis)**		
	Galloway Creek	**Two-run Branch**	**Pindell Branch**
Residential	227 (16)	181 (21)	45 (9)
Commercial	11 (1)	3 (0.3)	0
Roads	73 (5)	20 (2)	7 (1)
Pasture and hay	36 (3)	69 (8)	6 (1)
Raw crops	156 (11)	81 (9)	80 (16)
Forest	808 (58)	300 (34)	371 (73)
Wetlands	25 (2)	209 (24)	0
Open space	60 (4)	18 (2)	0
Total acreage	*1,396*	*881*	*509*

3.3.6 Water Quality

Water quality has been monitored at the Jug Bay component since 2003 through three continuous monitoring (CONMON) stations. These stations are part of the NERRS system wide monitoring program (SWMP):

- Iron Pot Landing on Western Branch (38° 47' 45.60 N, 76° 43' 14.88 W),
- Jug Bay Railroad Bed (38° 46' 52.68 N, 76° 42' 49.32 W), and
- Mataponi Creek (38° 44' 35.88 N, 76° 42' 26.64 W) (Figure 3.3.14).

The stations monitor both physical and chemical water quality parameters. Eight parameters (temperature, specific conductivity, salinity, percent oxygen saturation, dissolved oxygen – DO, depth, pH, and turbidity) are measured *in situ* with a YSI 6600, and measurements are recorded every fifteen minutes. Grab samples are collected twice a month and sent to Chesapeake Biological Laboratory to be analyzed for the following parameters: chlorophyll *a*, ammonium (NH_4), nitrite (NO_2), nitrite+nitrate ($NO_{2/3}$), phosphate (PO_4), total suspended solids (TSS), total volatile solids (TVS), total nitrogen (TN), and total phosphorus (TP). All three of these stations are still active, and data can be downloaded from the Maryland Department of Natural Resources eyesonthebay.net website. Two CONMON stations that are no longer active were established in July of 1995 and successfully collected *in situ* water quality parameters through December of 2002. Data collected from those and all stations can be downloaded from the Centralized Data Management Office (CDMO) website: http://cdmo.baruch.sc.edu/.

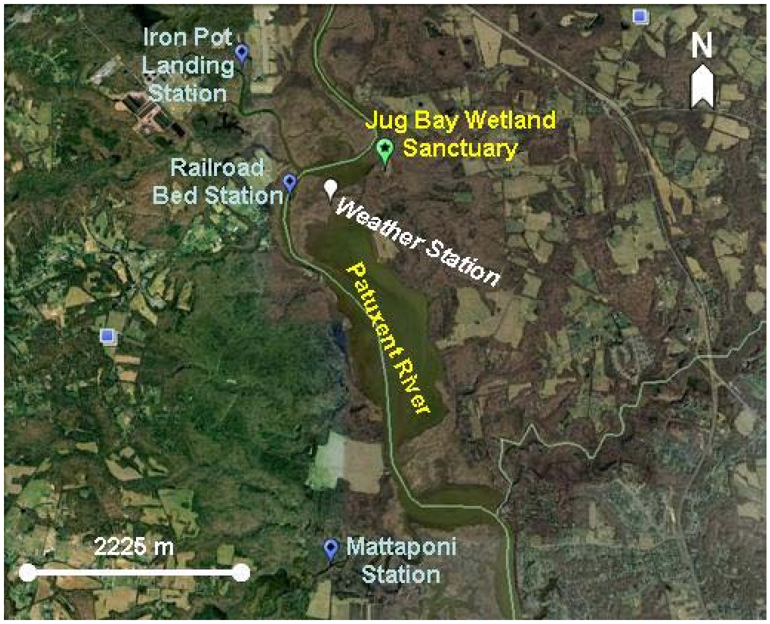


Figure 3.3.14 Location of continuous monitoring stations (CONMONs) at the CBNERR-MD Jug Bay component. CONMON stations are part of the NERRS system wide monitoring program (SWMP).

In addition to Reserve efforts, the Jug Bay Wetlands Sanctuary has been monitoring water quality in some marsh areas since the designation of this component in 1985 through the Jug Bay Water Quality and Nutrient Dynamics study. The study ended in 2009 in order to redirect efforts to a stream study established in November 2009. The goal of this water quality study was to determine the role of tidal freshwater wetlands in affecting water quality chemistry. It became volunteer driven in 1988 and became one of the largest volunteer efforts as well as the longest ecological study at the Sanctuary. Through the duration of the study, five sites were sampled for pH, water clarity, dissolved oxygen, and temperature. Water samples were collected and sent to the Chesapeake Bay Laboratory for nitrogen concentration analysis (Friebele 2001).

Swarth and Peters (1993) summarized the water quality data from 1987 through 1992 and concluded that Jug Bay marshes played an important role in reducing nitrogen concentrations through plant uptake and denitrification. Results during the growing season showed lower nitrate concentrations during the ebbing tidal cycle when water is flushing out of the marsh than concentrations in the river water before it flows onto the marsh during high tide. Dissolved oxygen saturation averaged between 80% and 90%, and dissolved oxygen levels were generally lower in the marsh sites compared to the river site (Swarth and Peters 1993). More complete results of the Water Quality and Nutrient Dynamics study through 2009 can be found at the Jug Bay Wetlands Sanctuary.

3.3.6.1 Dissolved oxygen

Water quality criteria for the desired dissolved oxygen levels have been established by the U.S. Environmental Protection Agency (USEPA) for five essential aquatic habitats (Table 2.3.1, Otter Point Creek Water Quality). To meet the criteria, dissolved oxygen levels must remain above 5 mg per liter; Jug Bay currently meets this criterion. An analysis of dissolved oxygen (DO) and depth data from the three Jug Bay Reserve CONMONs for the time period of April 2003 through December 2009 showed that the average surface DO was 8.53 mg/liter for Iron Pot Landing, 8.62 mg/liter for Railroad Bed, and 6.74 mg/liter for Mataponi Creek (Figure 3.3.15).

All average surface dissolved oxygen values from all three CONMON stations were above the designated criterion of 5 mg/liter. However, it is apparent that the Mataponi Creek station has a lower surface dissolved oxygen and average water depth compared to the other two stations located further upriver. Lower DO values at Mataponi Creek may be the result of various factors: first, the depth at this station is about 0.5–0.8 m (1.6–2.6 ft) shallower than the other two stations and water quality parameters in shallower environments are more prone to fluctuate as a response to atmospheric conditions such as temperature and wind. For example, warmer temperatures during the summer months warm up shallower systems faster reducing the ability of oxygen to dissolve in water. Second, Mataponi Creek is the only station where the bottom is colonized by SAV, potentially leading to lower DO values as a result of decomposition of accumulated organic matter. This may occur particularly during the end of the growing season and SAV dieback. Third, Mataponi Creek is narrow, which limits water exchange, creating a low energy environment.

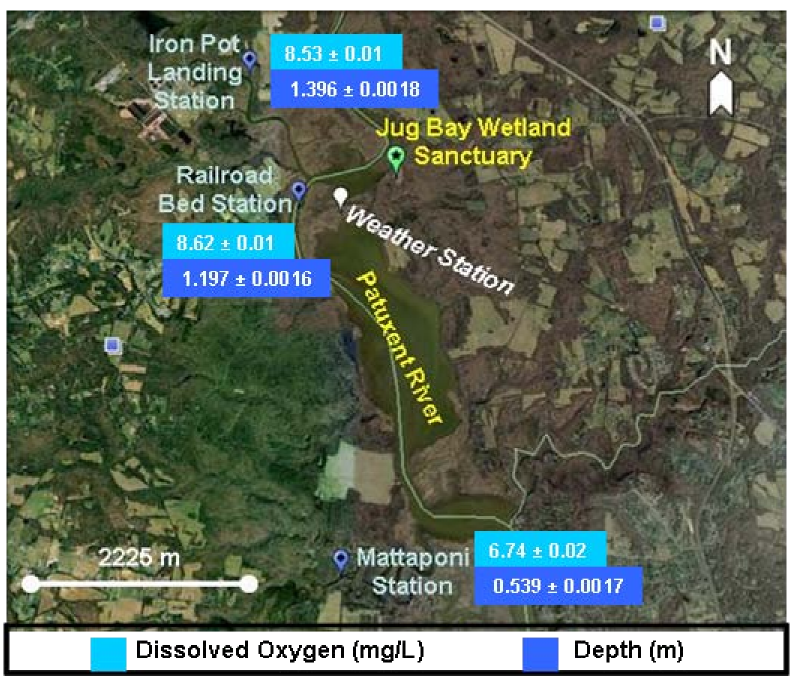


Figure 3.3.15 Average dissolved oxygen (mg l^{-1}) concentrations and water depth (m) for the period of April 2003 through December 2009 from three CONMON stations located at Jug Bay: Iron Pot Landing, Railroad Bed, and Mataponi Creek.

While the average DO values are above 5 mg l^{-1} for all the stations, there are times during the year when values dip lower. Low dissolved oxygen levels commonly occur in summer during low tides. Low dissolved oxygen levels may also be a response to biogeochemical processes:

decomposition (where organic matter converts to ammonium), nitrification (where ammonium converts to nitrate), and denitrification (loss of nitrate as nitrate is converted to nitrogen gas). These processes take place naturally in wetlands as they are important mechanisms by which excess nitrogen is lost to the atmosphere. The uptake, cycling, and loss of nitrogen improves water quality because excess nitrogen is a critical limiting nutrient that fuels algal blooms (Swarth and Peters 1993).

Other water quality parameters collected as part of the long-term water quality monitoring include pH, salinity, and temperature (Table 3.3.4). The Jug Bay component lies within the tidal freshwaters of the Patuxent River; therefore, the average surface salinity of 0.18 ppt is considered normal for this area. The average surface pH value is 7.01 which is within the normal range for freshwater systems (Weller 1994). Finally, the average water temperature for all three stations was 16.2 °C (61 °F).

Table 3.3.4 Average values of water quality parameters monitored through three continuous monitoring stations at Jug Bay. Stations are listed from upper to lower river: Iron Pot Landing, Railroad Bed, and Mataponi Creek.

Station	**Total Depth (m)**	**pH**	**Salinity (ppt)**	**DO (mg l^{-1})**	**DO (%)**	**Temperature (°C)**
Iron Pot Landing	1.396	7.22	0.20	8.53	84.8	16.1
se = standard error	0.0018	0.001	0.0004	0.01	0.06	0.04
Railroad Bed	1.197	7.16	0.18	8.62	84.0	15.8
se	0.0016	0.001	0.0005	0.01	0.09	0.04
Mataponi Creek	0.539	6.64	0.15	6.74	66.5	16.6
se	0.0017	0.007	0.0006	0.02	0.19	0.05
Average	1.044	7.01	0.18	7.96	78.4	16.2
se	0.0017	0.003	0.0005	0.01	0.11	0.04

Average values were calculated based on data collected from 2003-2009.

3.3.6.2 Water Clarity

Water clarity or turbidity describes how clear or cloudy the water is. Sediments and nutrients (by contributing to algal growth) are critical contributors to turbid waters and come from a variety of sources. Rain (as runoff) and snow melts and the occasional overflows from local wastewater treatment plants are probably the main vectors bringing excess sediments and nutrients into the Patuxent River. As sediments settle and are deposited, water currents, wind, and ice flows may cause re-suspension of sediment particles which contributes to decreased water clarity. By 2003, the volunteer-driven Water Quality and Nutrient Dynamics study showed that water clarity in the Patuxent River's main channel had an increase (although not significant) compared to values reported during the start of the study in 1988 (Miller 2003). Yearly and average turbidity values were determined from the Reserve's three CONMON stations for the period of April 2003 through December 2009. Average turbidity values were greatest at the Railroad Bed station and lowest at Mataponi Creek (Figure 3.3.16).

Figure 3.3.16 Average turbidity (NTU) values for the period of April 2003 through December 2009 for three CONMON stations at Jug Bay: Iron Pot Landing, Railroad Bed, and Mataponi Creek.

Higher turbidity values at the Railroad Bed station may be due to the location of the CONMON station along the main stem of the Patuxent River. In this position, it is more susceptible to boat traffic re-suspension and to runoff from surrounding residential properties located at the riverfront. The Iron Pot Landing station is located within a tributary off of the main stem; however, it is still susceptible to boat traffic and runoff from the western branch watershed. Average values at the Mataponi Creek station were nearly seven NTUs less than values at the Railroad Bed station. The Mataponi Creek station is further off of the main stem and it is the only station with significant amounts of SAV colonizing the bottom. SAV slows water flow and promotes sediment trapping, which contributes to increase water clarity.

Yearly turbidity values for each Jug Bay CONMON stations for the same time period of April 2003 through December 2009 are presented in Figure 3.3.17. Similarly to the overall averages, the Railroad Bed station showed consistently higher turbidity values than the other two stations. Average turbidity at both Iron Pot Landing and Mataponi Creek stations was similar through time. Both stations show a slight turbidity decrease from 2004 through 2007 while averages increased at the Railroad Bed station during the same time period (Figure 3.3.17).

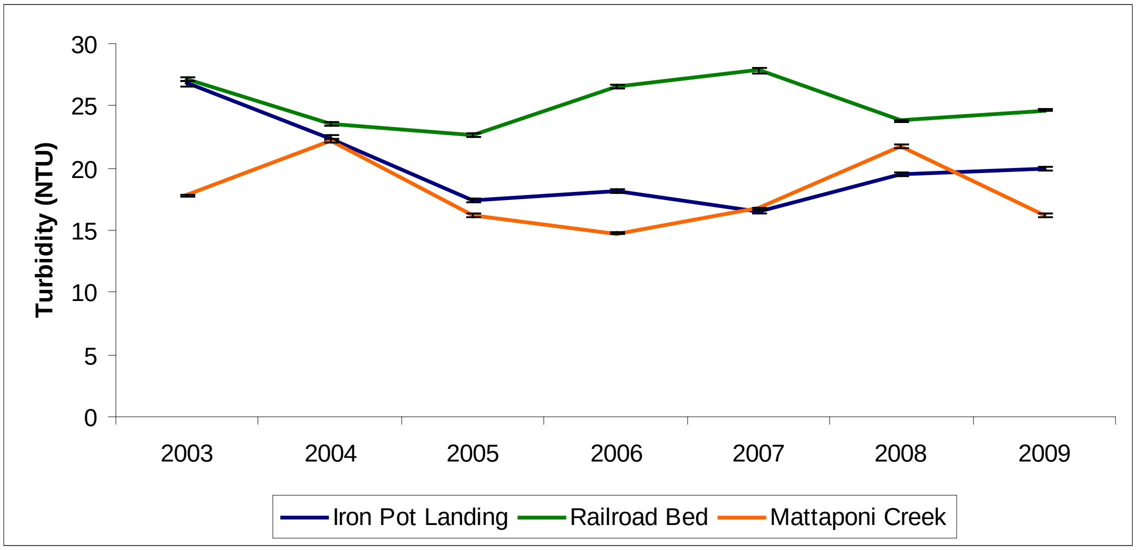


Figure 3.3.17. Average yearly turbidity (NTU) values estimated from three CONMON stations in Jug Bay: Iron Pot Landing, Railroad Bed, and Mataponi Creek for the period of April 2003 through December 2009.

Regarding stewardship for the health of our Chesapeake Bay waters, it is important to mention the story of retired U.S. Senator Bernie Fowler and the “Wade-In tradition”. Senator Fowler is not only known for his service in Congress, but also for his enthusiasm toward Patuxent River and Chesapeake Bay water quality restoration. For the past 23 years, Senator Fowler has hosted an annual Wade-In event at Broomes Island, Maryland where he conducts his well known “sneaker test.” Every second Sunday in June, he along with hundreds of enthusiastic local community members “wade” into the water with white sneakers to quantify how deep the sneakers can be seen (Figure 3.3.18). In June of 2009, Senator Fowler saw his sneakers through 25.5 inches of water. Similarly, in 2008, he saw his sneakers through 26 inches of water. While these values seem to be consistent, they do not compare to the 60 plus inches Senator Fowler saw from his childhood. He did not focus on the poor water quality, but on the actions that need to be taken to make the river and the Bay better for future generations. Since Senator Fowler’s first wade-in event in 1988, his efforts have motivated several other tributaries to host similar events to further promote citizen awareness on water quality and bay restoration (Chesapeake Bay Program Article June 2009).

Figure 3.3.18. Senator Bernie Fowler wading in the Patuxent River along-side Governor Martin O'Malley and U.S. Reprasentative Steny Hoyer at the 23rd Annual Wade-In Event at Broomes Island, Maryland. Image courtesy of Patuxent Riverkeeper and the Chesapeake Bay Program (June 2009).

3.3.6.3 Chlorophyll *a*

The concentration of chlorophyll *a* (a photosynthetic pigment in phytoplankton) in aquatic ecosystems is used by scientists as an indicator of plankton growth and concentrtions in the water column. High chlorophyll *a* values indicate algal blooms, which are often caused by excess nutrients within the system. The criteria of trophic status within marine and freshwater systems characterized by mean chlorophyll *a* concentrations was cited by USEPA in 2003 (Table 2.3.4 of the Otter Point Creek Site Profile). Based on the table, freshwater systems could be considered eutrophic when chlorophyll *a* concentrations reach values of 6.7 to 10 µg l^{-1}. At Jug Bay, average concentrations were quantified for the period of April 2003 through December 2009 at three CONMON stations (Figure 3.3.19). Based on these averages eutrophic conditions are present at both the Railroad Bed and Mataponi Creek stations, but is particularly evident at the Railroad Bed station.

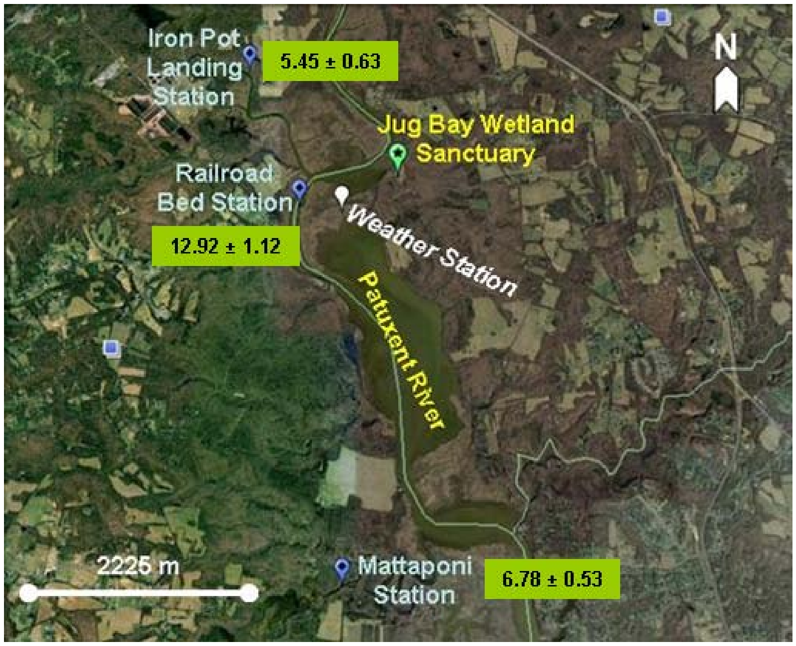


Figure 3.3.19 Average chlorophyll *a* concentrations (µg l^{-1}) at the three CONMON stations at the Jug Bay Reserve: Iron Pot Landing, Railroad Bed, and Mataponi Creek. Data are from April 2003 through December 2009.

A more detailed analysis of chlorophyll *a* values for the same period of April 2003 through December 2009 was conducted to determine the percentage of occurrences when chlorophyll *a* concentrations exceeded the criterion for algal blooms (Table 3.3.5). The Railroad Bed station was the only station where values exceed the criteria 25% or more for a single year. Interestingly, there were only three times when the percentages exceeded 20% and there were no occurrences equal or greater than 30%. The majority of the percent values were less than 15%. There were even instances in 2004 when the criteria were not exceeded at Mataponi Creek and Iron Pot Landing. Of the two stations, Iron Pot Landing exceeded the criteria the least which compares with the low average chlorophyll *a* values stated above.

Table 3.3.5 Chlorophyll *a* concentrations that exceed the criterion of 15 µg l^{-1} from the period of April 2003 through December 2009 for three CONMON stations located in Jug Bay. Values highlighted in red correspond to the regions where 25% or more of the concentrations exceeded the criterion during the seven year period.

Jug Bay Region	Chlorophyll *a* Concentrations Greater than 15 µg l^{-1} (%)						
	2003	2004	2005	2006	2007	2008	2009
Iron Pot Landing	3 (1)	0 (0)	1 (1)	1 (1)	5 (3)	4 (2)	9 (2)
Railroad Bed	9 (3)	11 (6)	8 (6)	11 (8)	25 (15)	9 (5)	27 (7)
Mataponi Creek	3 (1)	0 (0)	3 (1)	6 (2)	23 (7)	19 (5)	6 (1)

The numbers in parentheses correspond to the total number of observations used to calculate the Chlorohyll a criteria failure.

Scientists have also developed a tool to calculate the reductions in light penetration due to chlorophyll *a* and total suspended solid concentrations. USEPA (2003) set chlorophyll *a* concentrations criteria based on depth, total suspended solid concentrations, and water habitat type (Table 3.3.6). Average water depth, total suspended solid and chlorophyll *a* concentrations were quantified for the three CONMON stations from April 2003 through December 2009. The Mataponi Creek and Iron Pot Landing stations meet distinctly the water clarity criteria, while the Railroad bed station average falls close to breaking the water clarity criteria. Since the average depth value for Iron Pot Landing is between one and two meters, values could be interpreted one of two ways. Regardless, it is important to highlight that overall Jug Bay is not exceeding expected water clarity criteria.

Table 3.3.6 Chlorophyll *a* concentrations (μg l^{-1}) criteria based on total suspended solid concentrations (mg l^{-1}), depth (m) and shallow-water system habitat type. Areas in gray indicate where water clarity criteria are exceeded. Source: USEPA (2003).

Total Suspended Solids (mg $liter^{-1}$)	**Tidal-Fresh and Oligohaline**			**Mesohaline and Polyhaline**		
	Water-Column Depth (meters)					
	0.5 m	1 m	2 m	0.5 m	1 m	2 m
5	199	71	9	122	34	
10	171	43		95	8	
15	144	16		68		
20	116			42		

Patuxent River Embayment Characteristics			
Station	**Average Water Column Depth (m)**	**Average Total Suspended Solids (mg l^{-1})**	**Average Chlorophyll *a* concentration (μg l^{-1})**
Iron Pot Landing	1.396 ± 0.002	11.6 ± 1.22	5.45 ± 0.65
Railroad Bed	1.197 ± 0.002	14.9 ± 1.46	12.9 ± 1.12
Mataponi Creek	0.539 ± 0.002	5.97 ± 0.72	6.78 ± 0.53

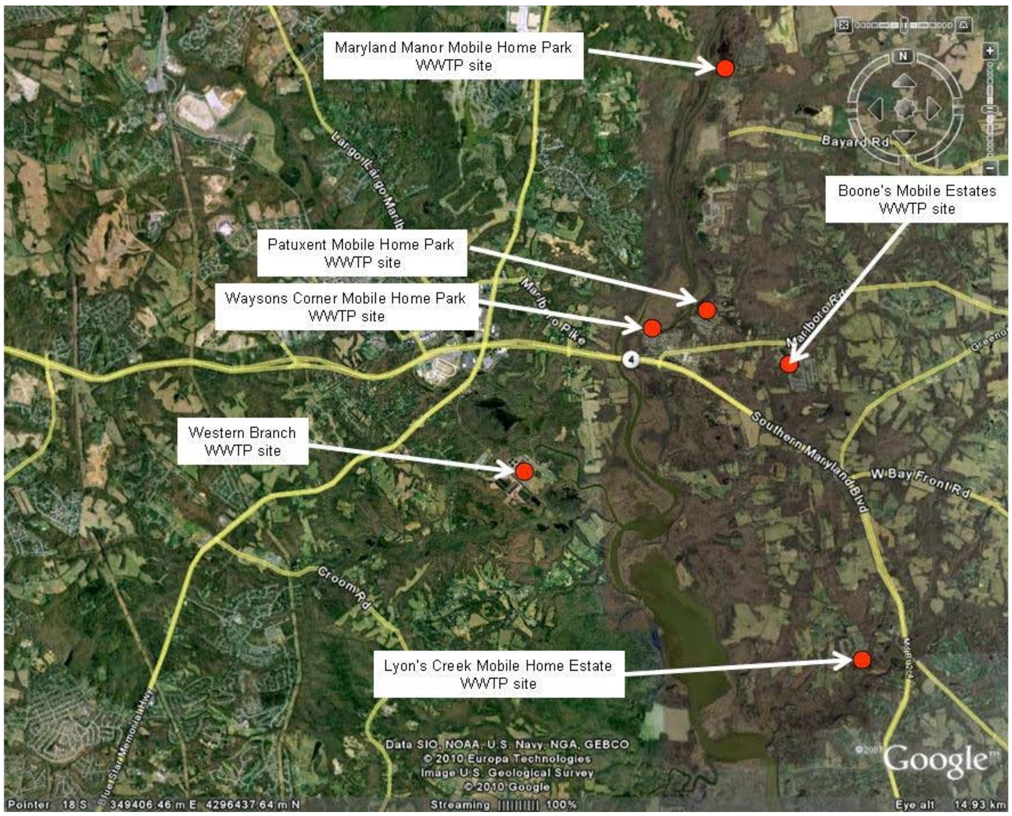
Average values were calculated from the time period of April 2003-December 2009.

3.3.6.4 Nutrients

The Patuxent River and the Jug Bay component, has been for many years a focal point for studying nutrient dynamics. Ziegler et al. (1999) assessed the fluxes of ammonium (NH_4) and nitrate (NO_3) within the sediment-water interface of the railroad bed marshes located near the Jug Bay Wetlands Sanctuary. Sediment cores were taken in July and August of 1992 and January of 1993. Results indicated the importance of Jug Bay marshes in nutrient cycling and water quality. Marsh sediments acted as a source of ammonium and a sink for nitrate, successfully transforming dissolved inorganic nitrogen (Ziegler et al. 1999).

The Patuxent River has been classified as a nutrient-overenriched tributary of the Chesapeake Bay primarily due to nutrient inputs from point and non-point sources, and atmospheric deposition (Jordan et al. 2003). Through the use of watershed-level models the concentration of nutrients and sediments within the Patuxent River has been positively correlated to the proportion of cropland and developed land in the watershed. It appears that changes in cropland coverage tend to produce larger shifts in nutrient concentrations than similar changes in developed land proportion (Weller et al. 2003). Additional modeling has been conducted for the Patuxent River watershed in an effort to predict water quality changes as a result of current and various land-use change scenarios, which represents a valuable tool for planning and management of both land-use and living resources (Lung and Bai 2003).

Locally the are six wastewater treatment plants, the largest being the Western Branch Wastewater Treatment Plant (WB-WWTP) which are important point sources of nutrients to the system (Figure 3.3.20). Approximately 40 million gallons of treated effluent from these plants enter the river daily and it has been estimated that 25% to 40% of nitrogen entering the Chesapeake Bay watershed comes from The Patuxent Wastewater Reclamation Facility located in Crofton, Maryland (Swarth and Peters 1993). Between 1991 and 1994, over $190 million was spent in upgrades to eight of the 25 treatment plants yielding a decrease in nutrient concentrations and an increase in SAV biomass within the tidal Patuxent (Naylor and Kazyak 1995).



Map: Courtesy of C. Swarth

Figure 3.3.20 Location of wastewater treatment plants (WWTPs) in the vicinity of the CBNERR-MD Jug Bay component.

Despite many WWTP upgrades, specifically to the Western Branch-WWTP, population growth stresses their ability to adequately treat wastes. This is particularly evident during major storm events, when partially treated waste overflows directly into the river. Other causes of overflows include unforeseen events such as power and mechanical failures. In an effort to determine the impact of these overflows in the Patuxent River's water quality, an analysis was conducted to compare nutrient concentrations before and after major overflows at a water quality station closest to the WWTP (Iron Pot Landing) and at a reference site (Mataponi Creek). Overall results of this analysis indicate that (1) major wastewater overflows represent an episodic short term loading of nutrients to the system, particularly total nitrogen and total phosphorus; (2) the continuing discharge of treated effluent and episodic overflows (in addition to other nutrient sources) seems to have changed the overall nutrient characteristics of the affected area as nutrient concentrations at the station closest to the Western Branch WWTP shows consistently higher values than those from the Mataponi Creek reference site (Table 3.3.7); (3) even though post-overflow high nutrient concentrations in the water decreased significantly soon after the event (approximately two weeks), it is important to remember that most of these nutrients remain within the system where they are transformed via biogeochemical processes, taken up by plants, or lost through denitrification processes (Delgado et al. 2007, unpublished data).

Table 3.3.7 Average nutrient concentrations summarized for the period of April 2003 through December 2009 from CONMON stations in Jug Bay, Patuxent River: Iron Pot Landing, Railroad Bed, and Mataponi Creek.

Jug Bay Station	**PO_4** mg P l^{-1}	**NO_2** mg N l^{-1}	**NO_3** mg N l^{-1}	**NH_4** mg N l^{-1}	**Total P** mg P l^{-1}	**Total N** mg N l^{-1}
Iron Pot Landing	0.1291	0.0074	0.5031	0.090	0.2834	1.27
se = standard error	0.0097	0.0004	0.0303	0.015	0.0181	0.04
Railroad Bed	0.0244	0.0119	0.7367	0.066	0.1456	1.41
se	0.0007	0.0004	0.0254	0.004	0.0045	0.03
Mataponi Creek	0.0169	0.0052	0.2530	0.047	0.1157	0.87
se	0.0917	0.0003	0.0143	0.003	0.0048	0.02
Average	0.0568	0.00820	0.4976	0.068	0.1816	1.18
se	0.0340	0.0003	0.0233	0.007	0.00914	0.03

Values are not adjusted to reflect changes in river flow.

Table 3.3.7 summarizes nutrient concentrations from the Reserve's three CONMON stations including phosphate (PO_4), nitrite (NO_2), nitrate (NO_3), ammonium (NH_4), total phosphorus, and total nitrogen. Average phosphate and ammonium concentrations decrease down-river from the Iron Pot Landing station to the Mataponi Creek station. Both nitrate and nitrite average concentrations were greater at the Railroad Bed and Iron Pot Landing stations compared to the Mataponi Creek station down-river. Because of the relative close proximity between Iron Pot Landing and Rail Road Bed stations, it is possible that the latter is influenced, in addition to other sources, from nutrients discharged by the local Western Branch WWTP.

Total phosphorus was greatest at the Iron Pot Landing station and was lowest at the Mataponi Creek station, while total nitrogen was greatest at the Railroad Bed station and lowest at the

Mataponi Creek station (Figure 3.3.21). The lowest values reported at the Mataponi Creek station may be an indication of two things: (1) as nutrient-charged water moves down-river flows through the marshes where nutrient uptake and denitrification occur and (2) it is a reflection of the more pristine conditions that characterize this station, which is surrounded mostly by wetland and upland forest, with no immediate impact from wastewater treatment plants as compared to the Railroad Bed and Iron Pot Landing stations.

Considering that the total nitrogen concentration is 0.65 mg l^{-1} and total phosphorus concentration is 0.037 mg l^{-1} (Wazniak et al. 2007), all the average concentrations reported in Table 3.3.7 for the Jug Bay area exceed the thresholds indicating the nutrient enrichment of the Patuxent River system.

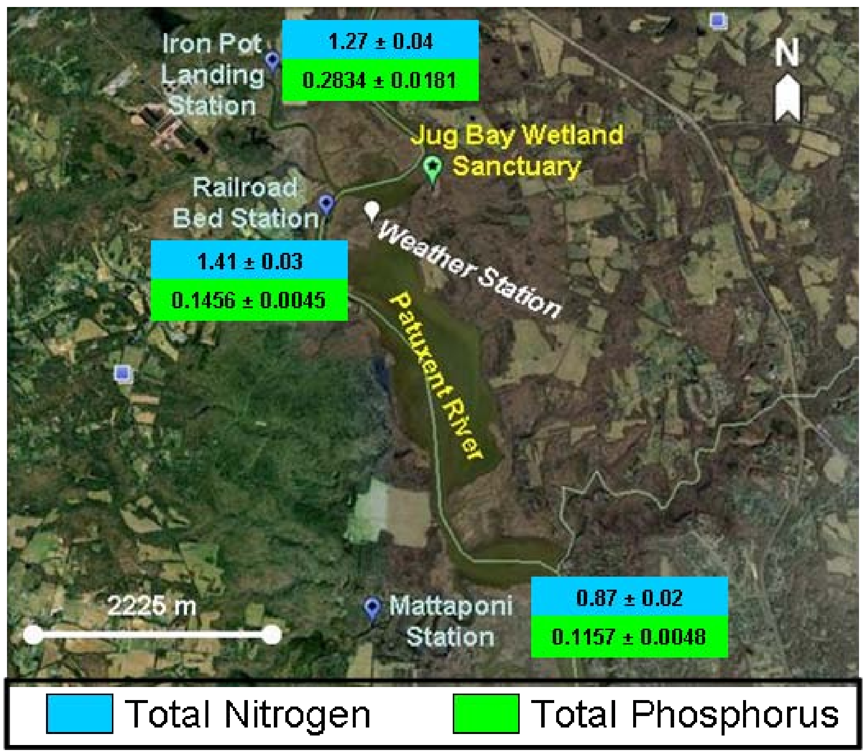


Figure 3.3.21 Average total nitrogen and total phosphorus concentrations (mg l^{-1}) for Jug Bay, summarized for the period of April 2003 through December 2009 from three CONMON stations: Iron Pot Landing, Railroad Bed, and Mataponi Creek.

One of the major roles that the Jug Bay Wetlands system plays within this area relates to its ability to improve water quality by trapping sediments and decreasing nutrient concentrations in the water through natural processes. Boumans (2002), Ziegler et al. (1999) and others have documented the role of Jug Bay marshes as a sink and transformer of nutrients. According to Costanza et al. (1997), the water purification services provided by tidal wetlands have an estimated economic value of \$6500 ha^{-1} yr^{-1}. Greene (2005) estimated Jug Bay marsh nutrient removal to be valued at \$10 to \$30 millions per year based on current control technologies.

3.4 BIOLOGICAL AND ECOLOGICAL SETTING

3.4.1 Tidal Freshwater Marsh

Tidal freshwater wetlands (TFW) are a distinctive type of transitional ecosystem located upstream from salt and brackish wetlands and downstream from nontidal freshwater wetlands. These wetlands are characterized by nearly freshwater conditions (less than 0.5 ppt salt content), plant and animal communities dominated by freshwater species, and daily tidal fluctuations. The soils are saturated, highly organic, and anaerobic (Baldwin et al. 2009).

Tidal freshwater wetlands (TFW) are ecologically important as critical habitat; they support a wide array of plant and animal life, with some organisms such as *Morone saxatilis* (rockfish) fulfilling part of their lifecycles in the waters (Mitsch and Gosselink 2000). Tidal freshwater systems are considered globally important because they sustain rare species and contain rare habitat. The varied habitat types and diverse vegetation of TFW provide the structure for complex communities of invertebrates, mammals, birds, fish, amphibians, and reptiles.

Jug Bay is among the largest TFW systems in the eastern United States (Boumans et al. 2003). The Jug Bay component, which is located in the middle Patuxent River estuary is made up of mostly freshwater tidal marsh habitats. The substrate is periodically exposed and flooded by semidiurnal tides. Low marsh and intertidal mudflats are often only irregularly exposed at low tide, whereas high marsh and scrub-shrub wetlands are only irregularly flooded at high tide but can also flood during storm events and wind tides. The salinity of the Patuxent River averages 0.5 ppt or lower annually, but can reach 2 ppt during periods of extended drought.

A distinctive characteristic of tidal freshwater systems, including Jug Bay, is that the vegetation is characterized by high species diversity and dominated by salt-intolerant freshwater plant species as compared to downstream wetlands with higher salinity (Odum et al. 1984, Odum 1988). Tidal freshwater wetlands are often divided into habitat types in which depth and duration of water inundation dictates where plants can grow, for example low marsh, middle-high marsh, scrub-shrub swamp, and riparian forest or swamp.

Plant communities within marsh transition zones are not distinctive, but instead share common species. However, in an effort to make these classifications, different methods are used to systematically separate distinct communities; for example, the classification system of plant communities of Maryland (Harrison 2004), which is part of the NatuReserve program. Often, each habitat or marsh zone is characterized by a few dominant species (Mitsch and Gosselink 2000, Pasternack et al. 2000, Leck and Simpson 1995, Simpson et al. 1983), always considering that true zonation is usually indistinguishable (Perry et al. 2009, Odum 1988). Competition among species, site-specific hydrology, and irregular microtopography all contribute to the indistinct vegetation zones found in tidal freshwater wetlands (Mitch and Gosselink 2000, Pasternack et al. 2000, Leck et al. 2009). Table 3.4.1 presents a short list of dominant plant species for the Jug Bay marsh, including the wetland zones where they are mainly found. A very comprehensive list of the wetland species of Jug Bay and other upland species can be found in the Jug Bay Wetlands Sanctuary website at http://www.jugbay.org/research/species_lists.

Table 3.4.1 Dominant wetland plant species found in the tidal freshwater marshes of Jug Bay.

Common Name	**Scientific Name**	**Wetland "Zone"**
Spatterdock	*Nuphar lutea*	Low
Pickerelweed	*Pontedaria cordata*	Low to mid
Wild rice	*Zizania aquatica*	Low to mid
Arrow-arum	*Peltandra virginica*	Low to mid
Rice cut-grass	*Leersia oryzoides*	Mid
Common reed	*Phragmites australis*	Mid
Cattails	*Typha spp.*	Mid
Sweetflag	*Acorus calamus*	Mid to high
Halberd-leaved tearthumb	*Polygonum arifolium*	Mid to high
Bur marigold	*Bidens laevis*	High
Buttonbush	*Cephalanthus occidentalis*	High
Marsh hibiscus	*Hibiscus moscheutos*	High
Jewelweed	*Impatiens capensis*	High

According to the Jug Bay rare plants list (www.jugbay.org/research/species_lists) several species of plants occurring in the marsh are rare, threatened or endangered. *Chelone obliqua* (red turtlehead), which is considered threatened in Maryland, is an obligate wetland plant that has flowers frequented by butterflies and hummingbirds. *Galactia volubilis* (downy milk pea) is an upland plant that can be found in the scrub-shrub habitat and is endangered, threatened, or extirpated in surrounding states. Other rare, threatened or endangered plants include *Desmodium laevigatum* (smooth tick-trefoil), *Desmodium viridiflorum* (velvety tick-trefoil), *Lespedeza stuevei* (downy bushclover), *Rhynchosia tomentosa* (hairy snoutbean), *Carex exilis* (coast sedge), *Carex hyalinolepis* (shoreline sedge), *Carex lupuliformis* (hop-like sedge), *Carex vesicaria* (inflated sedge), *Carex vestita* (velvety sedge), *Matelea carolinensis* (anglepod), *Matelea oblique* (climbing milkweed), *Platanthera blephariglottis* (white fringed orchid), *Platanthera ciliaris* (yellow fringed orchid), and *Platanthera flava* (pale green orchid).

Rare and threatened animal species include *Enallagma traviatum* (slender bluet), *Euphydryas phaeton* (Baltimore checkerspot), *Haliaeetus leucocephalus* (bald eagle), *Ixobrychus exilis* (least bittern), *Macromia illinoiensis georgina* (Georgia river cruiser), *Porzana Carolina* (sora rail), *Progomphus obscures* (common sanddragon), *Somatochlora linearis* (mocha emerald).

Great efforts have been made to preserve the vegetation and wildlife at Jug Bay, and there is much interest in continued preservation despite present and future threats. Because Jug Bay is subject to anthropomorphic and natural changes in hydrology, predicting the responses of the plant communities to such changes can help park managers determine whether specific habitats are vulnerable.

Several studies have examined the year-to-year and geographical changes in plant species and communities. Baldwin et al. (2001) found that flooding patterns are an important effect controlling plant species composition in tidal freshwater marshes from year to year. Their research shows that species diversity in these communities will be reduced by hydrological changes. Parker and Leck (1985) found that vegetation zonation patterns in tidal freshwater marshes are mainly governed by attributes of the species and the level of stress experienced during the early growing season, as opposed to seed bank abundances and composition. Plant species are assembled in a zonation pattern according to the amount of time and depth of inundation they receive. It is the hydrological influence within the marsh that determines which plant species will grow in which areas. Both of these studies (Baldwin et al. 2001, Parker and Leck 1985) point to the importance of hydrology as the main factor governing the patterns in the vegetation communities of tidal freshwater wetlands (TFW). Hydrological changes which may occur from sea level rise, changes in watershed land use, and/or geologic land subsidence will impact the plant communities and as a result also the animal communities of Jug Bay.

Other research has studied the importance of seed banks in determining spatial and temporal changes to TFW species distribution and composition. Many plants of tidal freshwater marshes produce copious amounts of seeds, some of which accumulate in the sediments every year producing seed banks (Leck et al. 1987). As a result of different species requirements for seed germination and growth, seed banks create the opportunity for species variability in different parts of the wetland and from year to year (Leck and Simpson 1993).

In an effort to monitor changes in Jug Bay's marsh plant communities, a long-term vegetation study was conducted from 1994 to 2008. A total of nine transects were established in different wetland habitats within the Jug Bay north and south Glebe marsh and measured in 1994, 1995, 2007, and 2008 using the line-intercept method. An analysis of the data collected through this monitoring effort shows relatively minor variability in the marsh community during the 14-yr study period (Swarth et al., unpublished data). This seems to be indicative of the current stability of the wetlands at Jug Bay. There were only a few cases where changes in some areas were observed for some key species; for example Figure 3.4.1 shows a decrease in the importance value of *Peltandra virginica* and *Acorus calamus* and an increase for *Pontederia cordata* through the study period.

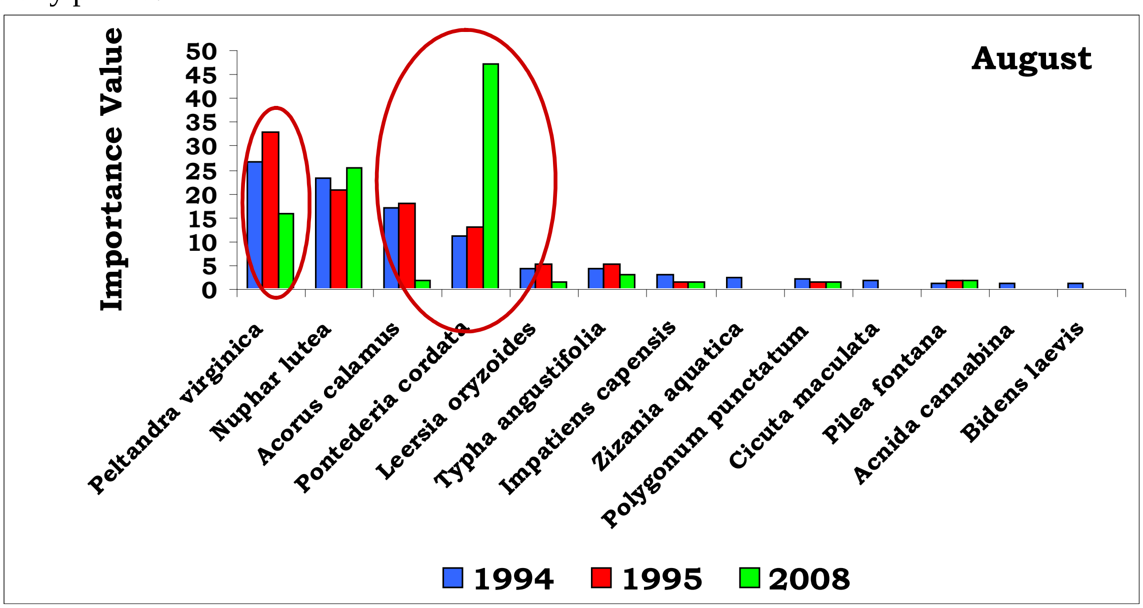


Figure 3.4.1 Importance values of marsh emergent vegetation species along transect at Jug Bay.

As a way to continue the monitoring started in 1994, a new longterm monitoring effort that covers a larger marsh area was started in 2008 by the CBNERR-MD research program. The main purpose of this program is to monitor the wetlands of Jug Bay as they may respond to impacts from climate change (particularly sea level rise) and watershed land use changes. This complements current water quality monitoring and other sedimentation related studies. Five transects were located within the vicinity of each of the existing CONMON stations for a total of 15 emergent vegetation transects (Figure 3.4.2). Measurements follow established NERRs protocols for sampling of marsh emergent vegetation as indicated by Moore (2009).

Figure 3.4.2 Location of marsh emergent vegetation transects within three main areas of the Jug Bay wetland system: Western Branch, Railroad Bed, and Mattaponi Creek.

Preliminary results of this monitoring effort show that approximately 78 different species of plants have been reported among the three sampling areas, although only about 25% of them could be considered relatively common. Some of these commom species are *Eleocharis* spp., *Hibiscus moscheutos, Leersia oryzoides, Mikania scandens, Murdannia keisak, Nuphar lutea, Peltandra virginica, Polygonum arifolium, Polygonum sagittatum, Sagittaria latifolia, Schoenoplectus fluviatilis, Sparganium eurycarpum, Typha* spp., and *Zizania aquatica* among others. Specific location of these species relative to the low marsh, middle-high marsh or scrub-shrub swamp is dependent upon the marsh habitat characteristics, particularly flooding conditions.

In Jug Bay a total of six estuarine intertidal habitats have been identified to facilitate the study of plant communities and their classification. These habitats are: subtidal and open water, pioneer mudflat, low marsh, middle-high marsh, scrub-shrub swamp, and riparian forest or swamp. Each of these will be described in the following sections.

3.4.1.1 Subtidal and open water

The Patuxent River runs through Jug Bay and is fed by a network of streams. Tidal flooding, groundwater hydrology, rain events, geomorphology and harmful agricultural practices all contribute to the variety of aquatic habitats in this estuarine system. Subtidal and open water habitats comprise 102 hectares (251 acres) of the component and are characterized by flowing water including the deeper tidal river, tidal streams, and non-tidal streams. The riverine system consists of linear aquatic habitats of flowing, non-tidal waters with a discrete stream channel. Stream and riverine habitats can transition into palustrine (marsh and swamp) habitat, estuarine intertidal habitats, or are bordered by steep banks of sand or gravel shoreline with sparse vegetation.

Submerged aquatic vegetation

A significant portion of the CBNERR-MD Jug Bay component is composed of subtidal and open water habitat. One of the most important communities found within this environment is submerged aquatic vegetation (SAV). In the Chesapeake Bay, SAV is often restricted to shallow water depths (less than 3 meters at mean low water – MLW; Dennison et al. 1993). These non-flowering or flowering macrophytes grow completely underwater from April to October. They act as biological indicators of the ecological health of coastal ecosystems (Duffy 2006, Orth et al. 2006). SAV provides cirtical ecological services by reducing turbidity, stabilizing the shoreline, reducing erosion and improving overall water quality by filtering nutrients and sediments (Short and Wyllie-Echeverria 1996). SAV also serves as an important food source for aquatic animals, provides habitat for commercial fish and shellfish, and acts as a breeding and nursery ground for a variety of fish and wildlife (Short and Wyllie-Echeverria 1996, Beck et al. 2001). Subtidal and open water zones that are not colonized by SAV, generally become barren sediments composed mainly of sand, silt, and clay. These barren sediments do not support nearly the life that SAV does.

Historical and current state of SAV

A review of historical maps for the Upper Patuxent River (which includes the Jug Bay component; Figure 3.4.3) from the Virginia Institute of Marine Science (http://web.vims.edu/bio/sav/index.html) shows a significant improvments in SAV coverage from first records in 1985 when SAV coverage was about 6 ha (15 acres) compared to 54 ha (133 acres) recorded nine years later in 1994 (Figure 3.4.4). Since 1994 SAV coverage within this area has ranged between 45 ha (111 acres) (1995) to about 131 ha (324 acres) (2005), which was an unusual high value during the entire mapping period (Figure 3.4.4). Also, since 1994 underwater grasses have maintained a constant presence in this area showing an overall increase from 2001 to 2006. The reasons for temporal variability of SAV coverage in this area are unknown, but could be due to natural bed dynamics or influenced by environmental conditions, mainly temperature and light availability.

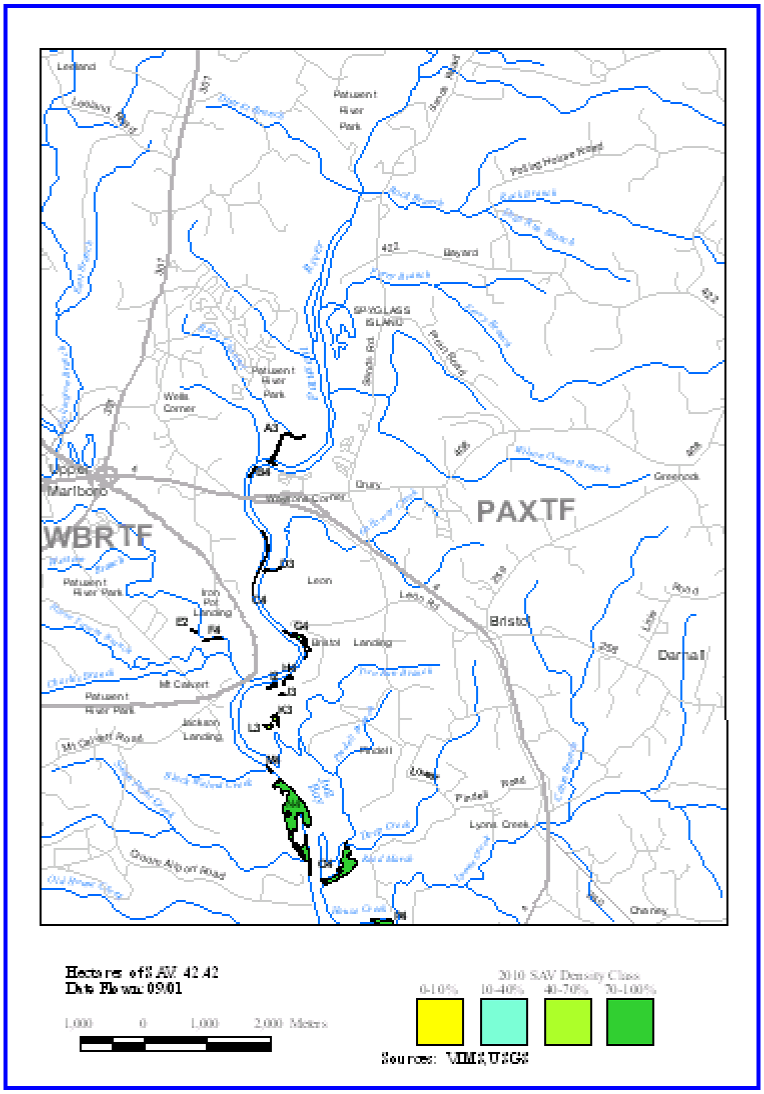


Figure 3.4.3 Submerged aquatic vegetation distribution at Jug Bay (see lower part of map). Map based on aerial surveys by the Virginia Institute of Marine Sciences (VIMS). This area corresponds to the Upper Patuxent River for 2010. Source: VIMS (http://web.vims.edu/bio/sav/index.html).

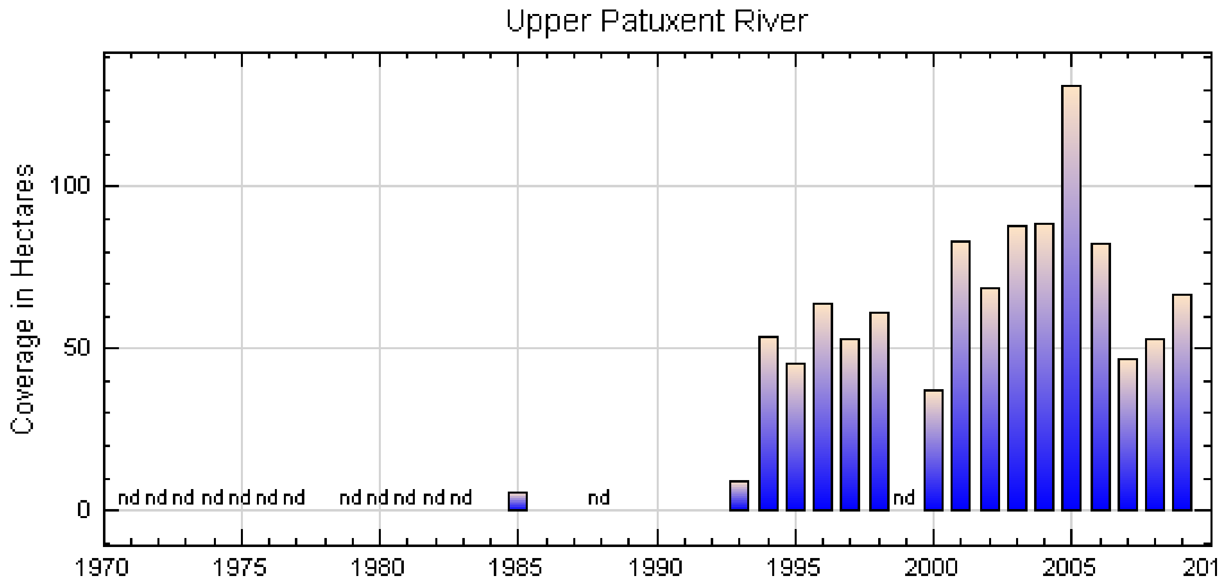


Figure 3.4.4 Long term distribution of submerged aquatic vegetation in the Upper Patuxent River (1971-2009); Figure 3.4.3. This area includes the Jug Bay component. The code "nd" indicates that the area was not mapped. Data source: Virginia Institute of Marine Science (http://web.vims.edu/bio/sav/index.html).

During 2004, and from 2007 through 2009, VIMS conducted ground surveys for the mapping area of the Upper Patuxent River. *Elodea canadensis* (common waterweed), *Hydrilla verticillata* (hydrilla; non-native), and *Najas minor* (spiny naiad; non-native) were found during each of the four surveys. *Ceratophyllum demersum* (coontail) and *Najas guadalupensis* (southern naiad) were found in 2004, 2007, and 2008. *Vallisneria americana* (wild celery) and *Zannichellia palustris* (horned pondweed); *Najas flexilis* and *Najas gracillima* (slender naiad); and *Chara* spp. (muskgrass and Alga) were found for only one year, in 2007, 2008, and 2009, respectively.

CBNERR-MD submerged aquatic vegetation monitoring

To monitor the status and spatial and temporal changes of the SAV community at Jug Bay, the CBNERR-MD research program established a monitoring effort that involves the sampling of six main SAV beds within and nearby the Jug Bay component (Figure 3.4.5). The main goals of the project are to detect short and long-term changes in species diversity, abundance, and dominance (particularly native versus non native species) and study the relationships between environmental parameters and SAV population dynamics.

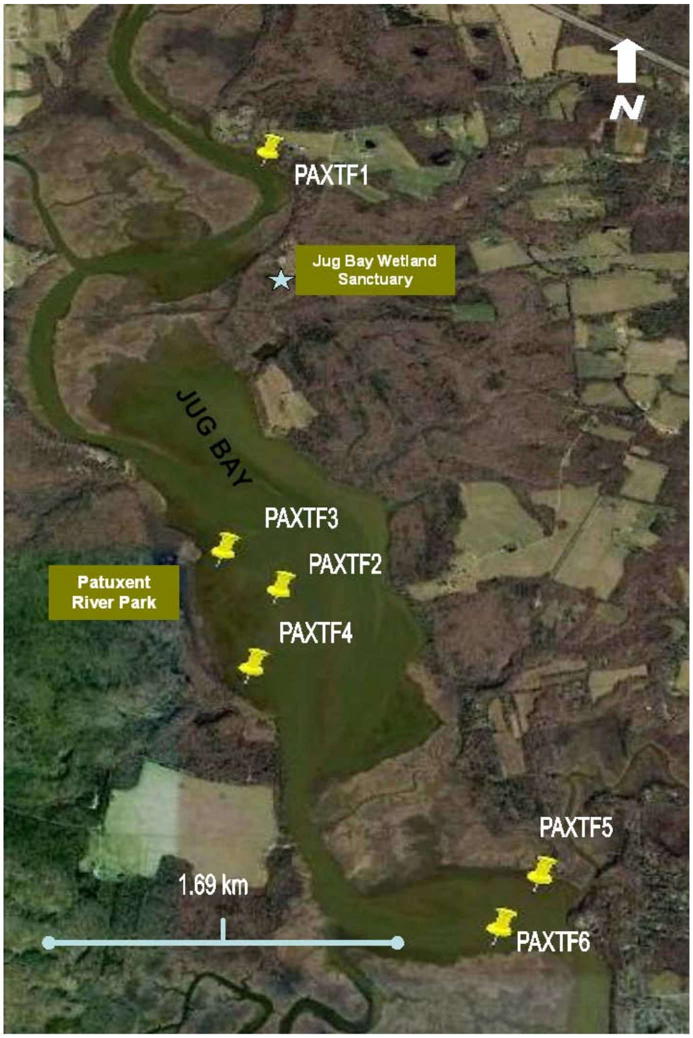


Figure 3.4.5 General location of submerged aquatic vegetation transects sampled by CBNERR-MD at Jug Bay.

SAV monitoring by CBNERR-MD began in 2007. CBNERR-MD established six, 60-meter (197 ft) long transects sampled at 10 meter (33 ft) intervals three times a year (June, August, and October). Often volunteers from the local community help with this monitoring effort. A modified oyster tong sampling technique is used, which is a suitable method for sampling when diving techniques are not practical (Figure 3.4.6). The characteristic shallow areas and the constant turbid conditions within the Patuxent River make the sampling of SAV by diving especially difficult. Water quality parameters (dissolved oxygen, temperature, conductivity, conductance, salinity, pH, and secchi depth), total depth, and a qualitative description of substrate type are recorded in addition to species presence and an indirect measure of species biomass (estimated through a volume displacement technique).

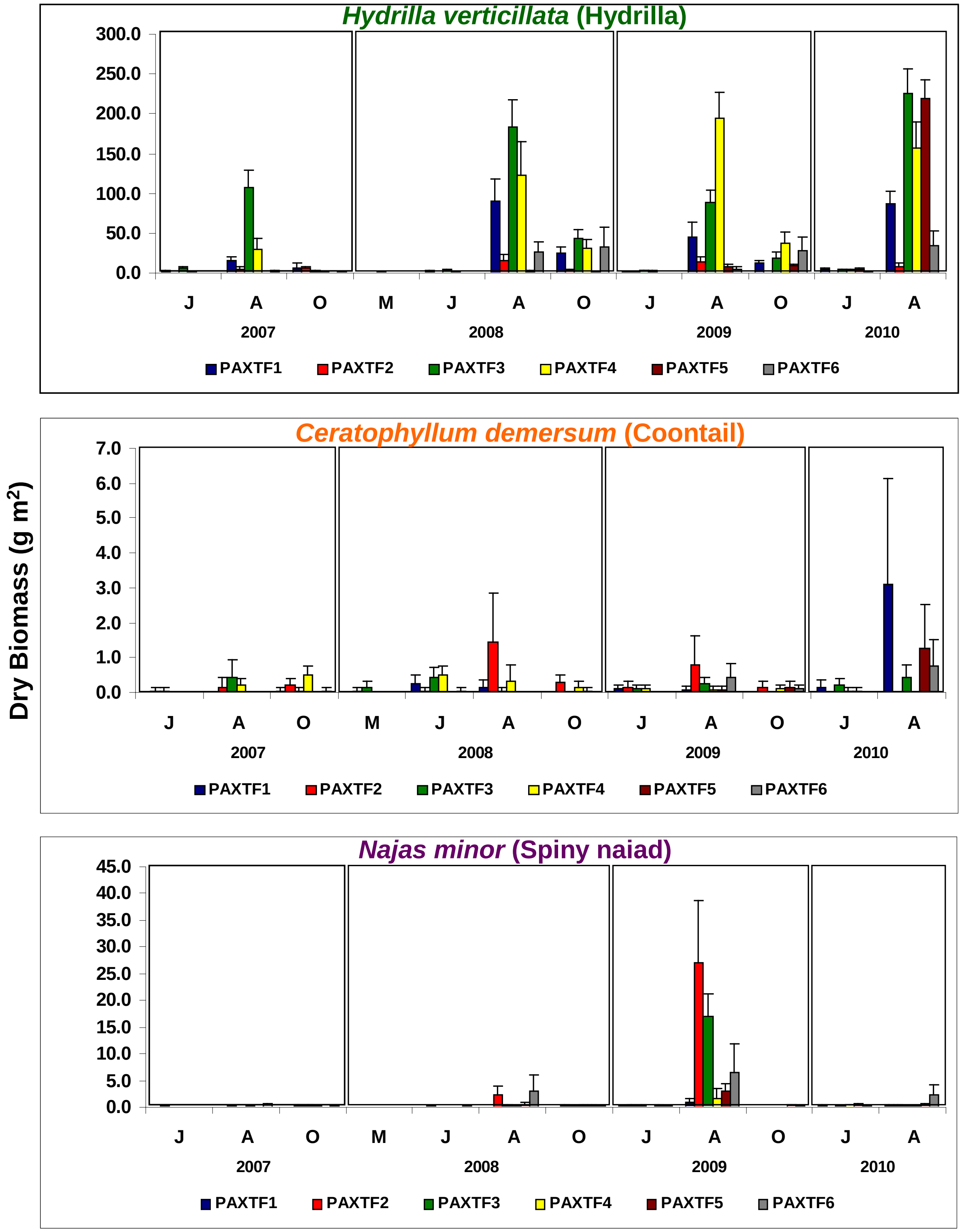


Figure 3.4.7 *Hydrilla verticillata*, *Ceratophyllum demersum*, and *Najas minor* dry biomass for six transects at Jug Bay sampled during June, August, and October from 2007-2010. Source: Delgado and Carroll (2010, unpublished data).

Hydrilla verticillata (hydrilla; Figure 3.4.8) is a non-native species which was first detected in the Patuxent River during a 1993 survey conducted by Maryland National-Capital Park and Planning Commission / Patuxent River Park in Back Channel and Mill Creek. Hydrilla is a strong competitor due to its ability to grow in oligotrophic (low nutrient) and eutrophic (high nutrient) conditions (Van et al. 1999). Furthermore, hydrilla allocates a majority of its biomass to shoot mass (Van et al. 1999), which allows for quick growth through the water surface developing a canopy and reducing light availability to other SAV species (Langeland 1996). Extensive hydrilla beds therefore tend to out-compete native underwater grass communities and impact water use by interfering with navigation of both recreational and commercial craft. However, similar to other SAV species, hydrilla provides habitat and food for some fish and wildlife, and helps to clean nutrients and sediments from the water.

Photo credit: P. Delgado

Photo credit: University of Florida, IFAS Center for Aquatic and Invasive Plants

Figure 3.4.8 Extensive hydrilla bed (left photo); close up of hydrilla (right photo).

SAV habitat requirements

The Chesapeake Bay Program developed water quality criteria by characterizing habitat requirements for SAV, which was based on a model for determining the "percent light at leaf" (Kemp et al. 2004). Kemp et al. (2004) estimated the minimum light requirement for SAV survival based on the amount of light reaching leaves as it passes through the water column and the epiphyte layer. SAV habitat requirements have also been estimated based on other parameters; for example, Dennison et al. (1993) described specific criteria for SAV survival including water depth, light attenuation through the water column, and the concentration of total suspended solids (TSS), chlorophyll *a*, dissolved inorganic nitrogen, and dissolved inorganic phosphorus. SAV habitat requirements differ depending on salinity regime and species.

In an effort to assess SAV habitat requirements for the Upper Patuxent River as described above, water quality data compiled from five monitoring sites located within this area were analyzed as part of the Maryland Tributary Strategy Patuxent River Basin Summary Report for 1985–2007. Results indicated that percent light at leaf, light attenuation, and concentration of suspended solids and phosphorus fail SAV habitat requirements for this region. Chlorophyll *a* levels, however, met the SAV habitat criteria (Maryland DNR 2007).

Restoration and outreach efforts

Considering that the Jug Bay underwater grass community is dominated by the non-native hydrilla, efforts have been made to restore native SAV species through volunteer and local community actions. In 2007, plantings of wild celery were conducted as part of the NOAA Restoration Day where Western Branch flows into Jug Bay (NOAA 2007). As part of this activity NOAA staff grew SAV in small tanks, which were then planted during a one-day field restoration event (more information about this event could be found at: http://restorationday.noaa.gov/). Another effort included the Chesapeake Bay Foundation’s Grasses for the Masses Program, which was organized in collaboration with the Jug Bay Wetland Sanctuary and CBNERR-MD. This program involved the participation of students, volunteers, and the local community in growing and planting native underwater grasses (Rohrer 2001, Chesapeake Research Consortium 2007). There have also been *Vallisneria americana* (wild celery) transplants near the Jackson Landing launch ramp at Patuxent River Park from 1999 to 2002. For the1999 and 2000 plantings there was evidence of plants flowering and seeding; however, although there was growth in the planting area in 2001 and 2002, by the fall season hydrilla had overtaken the wild celery.

3.4.1.2 Pioneer mudflat

The pioneer mudflat is a non or sparsely vegetated habitat that sometimes contains submerged aquatic vegetation. This habitat is found at a lower elevation than the low marsh habitat. Newly forming mudflats occur in areas prone to sedimentation such as at the mouths of streams where sediments are deposited; often adjacent to low marsh habitat. Mudflat habitat is also found in depressions within the low marsh and less frequently within high marsh habitats. This habitat can cover great expanses, particularly in areas with low elevation change (flat areas), and are often exposed at low tide. In Jug Bay, it is characteristic to find SAV colonizing some of the mudflats including *Hydrilla verticillata*, *Elodea canadensis*, and *Ceratophyllum demersum*.

At high tide, any plants present are completely submerged by 0.9 to 1.2 m (3 ft to 4 ft) of water. Fish, invertebrates, turtles, otters, beavers, swimming birds, and wading birds occupy the water foraging for food. As the tide goes out, most aquatic animals retreat to open, deep water areas. On the exposed mudflat, birds such as herons, shorebirds and dabbling ducks search for snails, crustaceans, and invertebrates.

3.4.1.3 Low marsh

The low marsh habitat occurs in shallow bays and shoals bordering intertidal mudflats or open water. The soil is inundated between 15 and 24 hours per day (Mitsch and Gosselink 1993) and is usually less than 2 m (6 ft) deep at high tide. The water depth depends on tide height (high or low tide), phase of the moon (spring tides vs neap tides), wind speed and wind duration, river flow (volume), precipitation (recent rains) and storms. Also, the release of water from the Patuxent River reservoirs at Rocky Gorge and Triadelphia can have an impact on depth. In some areas the marsh may be expanding due to sedimentation from upstream sources. Farming and development in the watershed over the last several hundred years caused surface soil to run off into the waterways delivering sediments into the marsh. The sediments settle out of the slowly moving water, especially during times of high tide as the momentum of the water reverses direction. As more and more sediment is delivered into the system, the marsh traps more sediment and forms sections of marsh in areas that were previously open water. Low marsh is situated adjacent to middle-high marsh with increasing elevation.

The low marsh plant community consists of perennial and annual herbaceous species dominated by broadleaf emergents. The plants are generally stand-forming species with mat-forming rhizomes that resist the erosive forces of flooding. Below ground, the finer roots of annuals occupy the upper soil while thicker perennial roots intertwine to form a dense network below ground (Baldwin 2004). The ability to withstand flooding plays a major role in vegetation community composition in the low marsh (Baldwin et al. 2001). The lowest elevations experience both the longest inundations as well as the deepest levels of water during high tide.

The dominant species in the lowest elevation is *Nuphar lutea* (spatterdock) which frequently occurs in large homogenous stands adjacent to open water (Figure 4.3.9). *N. lutea* is the first emergent species to appear (February in some years) at the start of each growing season. Submerged aquatic vegetation such as *Hydrilla verticillata*, *Elodea canadensis*, and *Ceratophyllum demersum* are also often present around the stems of the spatterdock. As elevation increases slightly, other low marsh species including *Peltandra virginica* (arrow arum) and *Pontederia cordata* (pickerel-weed) begin to emerge. They emerge later than *N. lutea*, flower during the summer months, and by August are yellow and wilting. In early summer, seedlings of emergent annuals such as *Zizania aquatica* (wild rice) and sometimes *Acorus calamus* (sweetflag) begin to grow and by midsummer overtop the low-growing plants, and flower and produce seeds during autumn. While the lowest elevations of the marsh are generally populated by spatterdock, the undisturbed low marsh areas which transition to middle-high marsh are quite species rich.

Photo credit: C. Swarth

Figure 3.4.9 Low marsh at Jug Bay dominated by *Nuphar lutea* (spatterdock).

Low marsh vegetation grows during the summer and fall months and dies back during the winter. Spatterdock, wild rice, arrow arum, and pickerelweed occupy expansive patches during the growing season, but during the fall and winter the above-ground portions of the plants die off, fall to the ground, and some material is also swept away by the water. The rhizomatous mats hold the subsurface in place but the surface mud is susceptible to erosion during the winter. In other areas of low marsh, dead cattails stalks remain in the marsh after the growing season is over, trapping moving sediments in the water during the winter months (Figure 3.4.10).

Photo credit: C. Swarth

Figure 3.4.10 Low marsh at Jug Bay in winter. Bare soil can be seen at the lowest elevation adjacent to open water. The dried stalks of cattail and marsh mallow (which persist in winter) in the foreground indicate slightly higher marsh elevations.

Zizania aquatica (wild rice) stands at Jug Bay represent a very important and characteristic community of the low marsh zone; it covers broad ares and is an important source of food and habitat for birds and other wildlife on the river (Figure 3.4.11). Both migrating and resident avian populations depend on wild rice as a major component of their diet. Since 1999 Patuxent River Park has led a highly successful restoration effort to sustain the wild rice stands in an effort to help maintain native plant and animal communities.

Research studies focusing on growth, herbivory, maintenance, and distribution of wild rice have been conducted on the site. In one study, Weiner and Whigham (1988) found that self-thinning in wild rice stands decreases the size variability within the stand. They attributed this tendency toward uniformity in individual plant size during density-dependent thinning as evidence of competition for light. This type of research is essential to understanding the growth of monoculture stands of wild rice.

Photo credit: G. Kearns

Figure 3.4.11 Low marsh with *Zizania aquatica* (wild rice) stands (light green) at Jug Bay, Patuxent River.

Herbivory of wild rice is a natural part of the freshwater tidal wetland ecosystem. Native waterfowl and wildlife have evolved to depend on wild rice as a major food source in the fall. Wild rice seeds are high in carbohydrates and migrating birds consume large amounts of it before making the fall migration trip to Florida, the Caribbean or Central America (Friebele 2001). These energy-rich seeds provide the fuel they need to power their southward flights. Millet and tearthumb seeds also provide important food for birds. A great threat to Jug Bay wild rice population is that it can be devastated by resident Canada geese in the early summer after the yound rice has germinated and is only a few inches tall. During the 1990s, herbivory by Canada geese was so deleterious to the wild rice that the stands suffered tremendous decline. Canada geese are an especially difficult problem due to the fact that they sustain a large population of year-round residents and at Jug Bay wild rice is a favorite food. The effect of this disturbance on plant communities at Jug Bay has been a focus of important research aimed at restoring the wild rice to its former abundance.

In 1999, Greg Kearns (Patuxent River Park Naturalist) placed 1-meter diameter wire fence enclosures in the rice stands as an experiment to determine the magnitude of the effect of herbivory by geese. After one season the results showed that fencing successfully deterred the geese from eating the rice. Tall, dense stands of wild rice grew within the enclosures whereas there was only bare mud and sparse rice cover outside of the enclosures (Figure 3.4.12; Carothers 1999). Haramis and Kearns (2001) investigated the problem in more detail by using three methods to control the herbivory: fencing, seeding, and goose hunting. They found that a combination of all three methods created an atmosphere conducive to wild rice recovery and restored the stands to almost pre-1990 levels (Figures 3.4.13 and 3.4.14). Baldwin and Pendleton (2003) also studied the interaction of wild rice herbivores and they found that low marsh study plots where exclusion fencing was used had significantly higher values of plant biomass, cover values, and leaf area index as compared to study plots that were accessible to animals such as resident Canada geese, *Cyprinus carpio* (commom carp) and *Ondatra zibethicus* (muskrat).

Photo credit: G. Kearns

Figure 3.4.12 Robust wild rice plants growing inside one meter enclosures at Jug Bay.

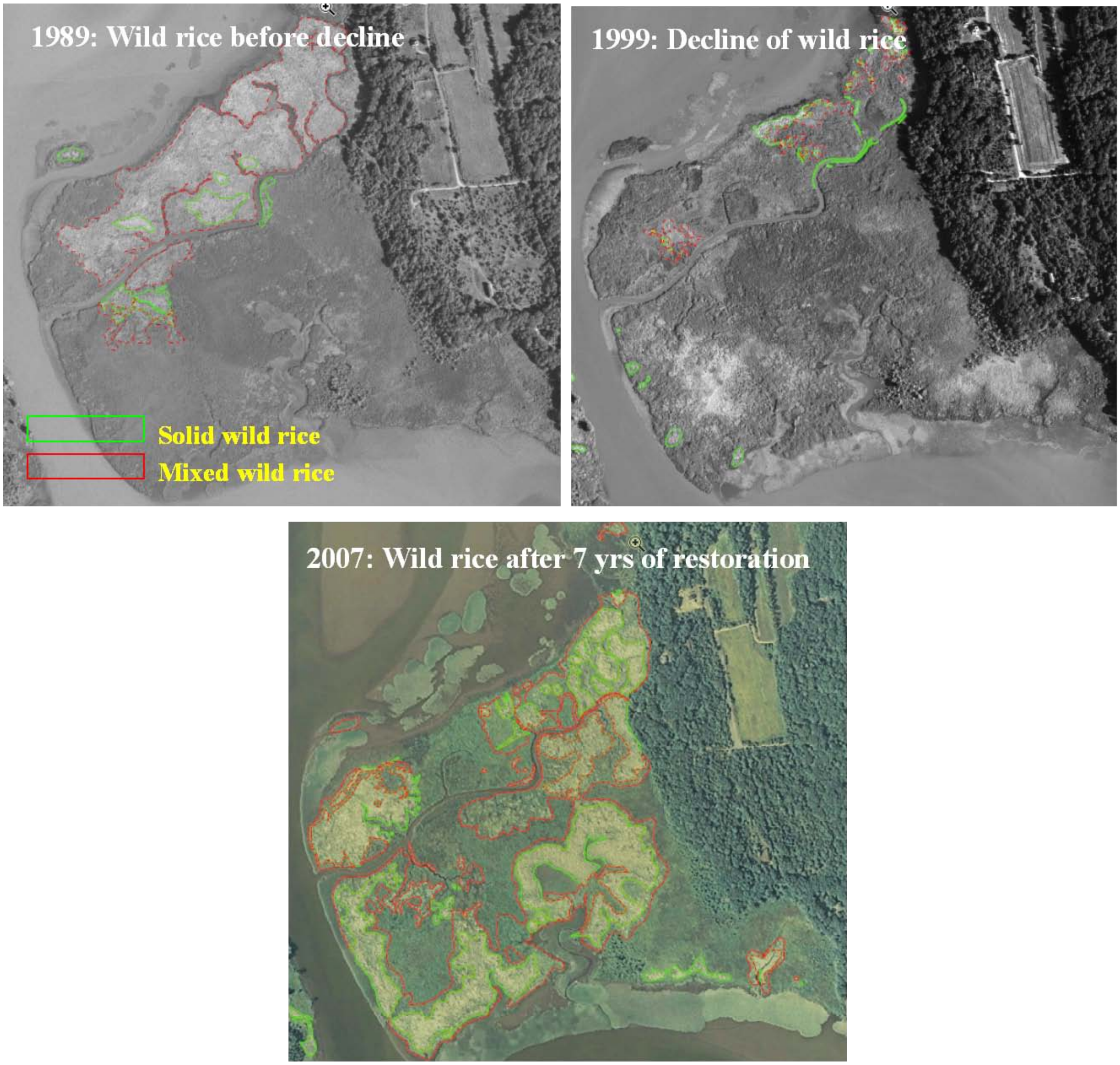


Figure 3.4.13 Aerial photos showing the extent of wild rice stands before herbivory by Canada Geese (1989), after herbivory (1999) and after restoration (2007). Source: Delgado et al. (2009, unpublished data).

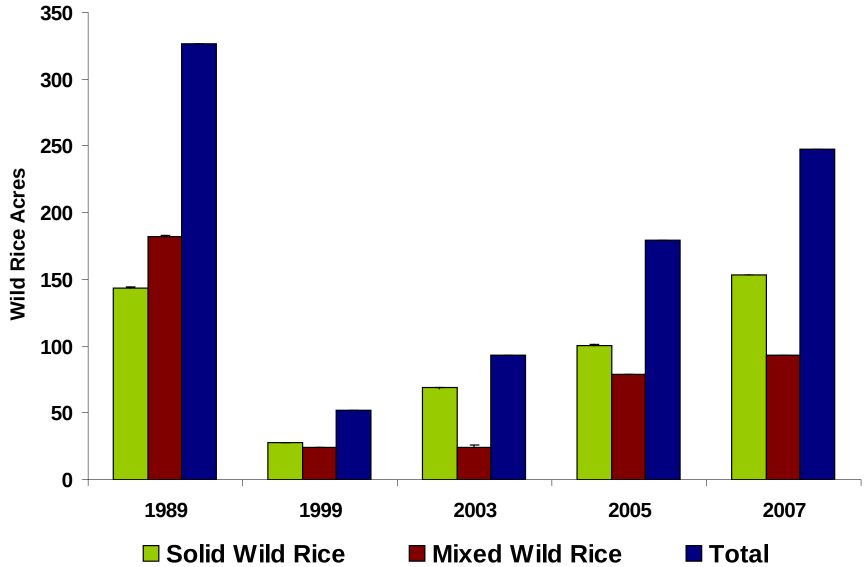


Figure 3.4.14 Wild rice change analysis. Study area = 9,650 acres. Results show that homogenous wild rice stands were restored to almost pre-herbivory values by 2007. Source: Delgado et al. (2009, unpublished data).

Fluctuating water levels from tidal flooding makes the low marsh a difficult place for many animals to live. Animals that use the low marsh are adapted to its unique hydrology. Typical animals found here include great blue herons, osprey, muskrats, river otters, and many other species of birds, animals, insects, and aquatic life. Great blue herons generally nest in the nearby riparian forest but forage in the low marsh and open water for fish Osprey, which feed exclusively on fish catch in open deep water and they utilize the many man-made nesting platforms placed in the low marsh by naturalists at Patuxent River Park.

3.4.1.4 Middle-high marsh

The middle-high marsh zone is characterized by slightly higher elevations that flood for shorter periods of time than the low marsh. The depth of flooding averages 0.5 m (1.6 ft) at high tide and depth varies based on the tidal amplitude. The marsh habitat at these elevations is under less hydrologic stress than the low marsh, but the plants undergo severe competition for space and light (Leck et al. 2009).

Using pollen and seed analysis from sediment cores, Khan and Brush (1998) found that the Jug Bay middle-high marsh formed within the last 100 years, most likely due to high sedimentation rates from agricultural runoff. This information is consistent with what is known about development and urbanization in the area over the last century. As farming and human expansion proceeded, soil run-off into the waterways caused suspended sediments to be delivered throughout the marsh. During tidal flooding, sediments settled out of the water column resulting in the formation of mudflats followed by plant colonization. As run-off continued, the marsh trapped more sediment forming larger flats of higher elevation.

Middle and high marsh habitat has a high diversity of herbaceous plant species. Characteristic species are *Typha angustifolia* (narrowleaf cattail), *Impatiens capensis* (jewelweed), *Acorus calamus* (sweetflag), *Carex* spp. (sedges), *Polygonum arifolium* (halberd-leaved tearthumb), (*Polygonum punctatum* (smartweed), *Leersia oryzoides* (rice cutgrass), and *Hibiscus moscheutos* (marsh mallow). *Polygonum arifolium* and *P. sagitatum* (tearthumb), vines with sharp recurved spines, grow over the other vegetation and dominates late in the growing season. *Peltandra virginica* (arrow arum), *Zizania aquatica* (wild rice), *Sagittaria latifolia* (arrowhead), and submerged aquatic vegetation can also be present, but more sparsely than in the low marsh.

The plants of tidal freshwater wetlands exhibit much more temporal variability in growth and dominance than do salt marsh plants (Odum 1988). Seasonal variation is apparent in the changing dominance values of species at Jug Bay as found by Laura Perry (1994). In the middle-high marsh, low growing perennials *P. virginica* and *A. calamus* dominate in early summer, but give way to other annuals and perennials that overtop and grow over them in mid- to late-summer (Odum 1988, Perry 1994). In late summer, *Z. aquatic*a, *Impatiens capensis, Bidens* spp., *H. moscheutos,* and *Acnida cannabina* reach peak biomass (Odum 1988, Perry 1994). The high species diversity of the middle-high marsh is measureable due to this seasonal succession, as other less prevalent species in a large species pool find niches during the transition of dominance (Simpson et. al 1983).

Year-to-year variation in marsh vegetation is another characteristic of Jug Bay wetlands. The community of species which grow in any given year is influenced by the hydrological structure of tidal flooding, variation in flooding, and by the specific germination and growth requirements of each species (Baldwin et al. 2001a). Because most marsh plants produce large quantities of seeds, the seed banks in the sediments are extensive (Leck and Simpson 1987). In comparing the seed bank to the resulting vegetation of various wetland areas, Parker and Leck (1985) found that vegetation zonation patterns in the freshwater tidal marsh are governed chiefly by attributes of the species and the level of stress experienced during the early growing season, as opposed to seed bank abundances and composition. Although the seeds of different species are found throughout the marsh, they only germinate and grow in areas that fulfill the species' requirements for germination and growth (Parker and Leck 1985). Competition between plants is also a major factor influencing plant composition in the middle-high marsh (Leck et al. 2009). Whereas seeds of many species may be abundant in the seed bank, the ability of a species to gain adequate space and light dictate whether that species will be successful in the middle-high marsh. Hydrological factors combined with the stress of intra- and inter- specific competition contribute to the year-to-year variation in species composition and dominance in the middle-high marsh.

In some areas of the middle-high marsh, *Phragmites australis* (common reed) dominates, creating almost pure, homogenous stands with few other species. However, on close inspection other species such as *Nuphar lutea* (spatterdock), *Pontederia cordata* (pickerelweed), and *Peltandra virginica* (arrow arum), *Typha angustifolia* (narrowleaf cattail), *Zizania aquatica* (wild rice), *Sagittaria latifolia* (arrowhead), *Impatiens capensis* (spotted jewelweed), *Acorus calamus* (sweet flag), *Carex* spp. (sedges) can often be found. Cronk and Fuller (1995) describe *P. australis* as a nuisance species that takes over habitat occupied by other plants, thus decreasing species diversity. Rice et al. (2000) used aerial photographs from the 1930s, 1970s, 1980s and 1990s to determine the distribution and expansion rate of *P. australis* in three tidal freshwater marshes, including the Jug

Bay Wetlands Sanctuary, and four brackish marshes. They determined that the three freshwater marshes had non-expanding populations of *P. australis*, most likely because it was present for decades, indicating a stable population. The brackish marshes, which were more recently colonized, had expanding populations of *P. australis*. This research built upon the earlier efforts of Shima et al. (1976), one of the first groups to use aerial photography and ground truthing to determine aspects of vegetation including species associations, vigor, growth habit, and successional stage.

For decades, park managers and wildlife officials have debated the management of *P. australis*. There is evidence, however, that *P. australis* stands may be helpful to marsh preservation. Rooth and Stevenson (2000) compared sedimentation and elevation change in marshes containing native *Spartina* spp. grasses with marshes containing the invasive *P. australis*. *P. australis* communities had both higher sediment deposition rates as well as higher rates of positive elevation change. In a related study, Rooth et al. (2003) found significantly higher rates of sediment accretion in *P. australis* communities, as well as increases in elevation as compared to adjacent areas occupied by *Typha* spp. and *Panicum virgatum.* The authors suggest that resource managers can use this information as they plan strategies for combating sea level rise in critical habitats.

Meyerson et al. (2000) compared freshwater tidal and nontidal marshes before and after eradication of monocultures of *P. australis*. They clearly showed rapid rates of colonization of other species after extirpation by fire or herbicide. This is probably due to the presence of many species in the seed bank being released from competition. Studies by Ailstock et al. (1990) support this trend for a nontidal freshwater marsh in Maryland. However, Meyerson et al. (2000) argue that repeated treatments may be necessary to prevent reinvasion of *P. australis*.

Although *P. australis* is considered a native species, there are questions as to why it has behaved like an invasive plant at Jug Bay and elsewhere. Paleoecological studies have shown that *P. australis* had a more limited prehistorical distribution, residing in the upper reaches of salt marshes in North America (Orson et al. 1987). Evidence clearly shows that in some areas human intervention in the hydrological cycles has caused it to spread and dominate (Roman et al. 1984). Other factors affecting its spread include pollution, development, mechanical disturbance, and the introduction of a genotype of the species that is particularly aggressive (Chambers et al. 1999).

3.4.1.5 Scrub-shrub swamp

Woody and herbaceous species occur together in the scrub-shrub dominated wetland. Scrub-shrub habitat occurs where the water is usually less than 0.5 m deep at high tide. It forms a zone between the middle and high marsh, and the neighboring uplands. The microtopography is variable, containing small hummocks (generally 2 m in diameter) and depressions with a diversity of species reflecting microsite hydrology: middle-high marsh species can be present in the depressions and upland shrub and tree species (facultative wetland plants) on the hummocks, while other areas are flatter and contain characteristic shrub and vine species. The canopy is of mixed height (trees may be 10 m high) and is relatively open. The soils are primarily organic with partially decomposed peat as well as fine sediments (Harrison 2004). The fruits and berries of shrub species provide a nutritious food source for migratory and resident songbirds.

Characteristic shrubs are *Alnus serrulata* (alder), *Cephalanthus occidentalis* (buttonbush), *Vaccinium corybosum* (highbush blueberry) *Ilex verticillata* (winterberry), *Lindera benzoin* (spicebush), *Viburnum dentatum* (arrowwood), *Cornus amomum* (silky dogwood), *C. foemina* (gray dogwood), and vines such as *Parthenocissus quinquefolia* (Virginia creeper), *Toxicodendron radicans* (poison ivy), and *Smilax rotundifolia* (greenbriar).

Characteristic ground layer species include *Onoclea sensibilis* (sensitive fern), *Impatiens capensis* (spotted jewelweed), *Polygonum* spp. (knotweeds), *Carex* spp. (sedges), and *Asclepias incarnata* (swamp milkweed).

The scrub-shrub swamp provides important food and cover for several birds listed by the Maryland Ornithological Society (MOS) as being threatened or endangered.

3.4.1.6 Riparian forest or swamp

This wetland habitat consists of woody and herbaceous species dominated by trees. The soil is typically wet and is subject to the action of wind tides and/or semidiurnal flooding which bring freshwater onto the floodplain. This forest habitat is found neighboring middle and high marsh, scrub-shrub wetlands, and upland plant communities. Riparian forest may be tidal or non-tidal. There is less research-based information available about the tidal forest habitats than about the tidal freshwater marshes (Baldwin et al. 2009).

Both tidal and non-tidal swamp forests occur at Jug Bay. The tidal hardwood swamp communities neighbor marsh habitat and at the furthest reaches of tidal influence grade into the non-tidal swamp forest. Tidal hardwood swamps are considered globally vulnerable to extinction because their range is restricted and less than 100 occurrences have been documented worldwide (NatuReserve 2009). These sites are rare because they occur in areas with a wide tidal range, a large volume of water flowing from upstream, and low coastal plain geographical relief. These three factors rarely occur together (Rheinhardt 1992).

The tidal swamp forest consists of hummocks and hollows in which upland tree species such as *Acer rubrum* more commonly occupy the hummocks, and woody species associated with wetter habitats, such as *Alnus serrulata* occupy the hollows (Duberstein and Conner 2009). At Jug Bay, Burke and Swarth (1997) indicated that the hummocks were one meter to three meters in diameter and had a firmer substrate than the soft, fine-grained sediments underlying the tidally-affected hollows.

The canopy tree species diversity is generally poor (Rheinhardt 1992). Compared to bottomland forests where the canopy is closed, the canopy of the swamp forest is relatively open, allowing sunlight to penetrate to the forest floor (Rheinhardt 1992). Characteristic trees are *Acer rubrum* (red maple), *Magnolia virginiana* (sweet bay magnolia), *Fraxinus pennsylvanica* (green ash), and *Nyssa sylvatica* (tupelo).

Kiviat (1997) surveyed a grove of *Ailanthus altissima* (tree of heaven) on the very edge of the Patuxent River, 50 to 400 m south of the mouth of Two Run Branch. Although the location of swamp forest is generally between lower elevation communities and upland areas, the *A. altissima* had large roots directly in the tidal waters. *A. altissima* is a hardwood species native to China that is invasive in disturbed areas and occurs widely along tidal shores from Connecticut to Maryland (Kiviat 2009). Elsewhere in the upland forests of Jug Bay, efforts to manage and control the spread of this noxious species are on-going.

The herbaceous and shrub layers of the tidal freshwater swamp forests are very species-rich and rival the number of species found in some of the most species-rich communities of the temperate zone, including the Appalachian cove forests and the mixed-mesophytic forests of the Cumberland Plateau (Rheinhardt 1992). The hummock and hollow topography, the mixed hydrology due to the microtopography, and the open canopy of this wetland create diverse micro-site conditions for vegetation. Common shrubs and vines are *Lindera benzoin* (spicebush), *Viburnum dentatum* (arrowwood), *Cornus amomum* (silky or knob-styled dogwood), *C. foemina* (gray dogwood), *Parthenocissus quinquefolia* (Virginia creeper), *Toxicodendron radicans* (poison ivy), *Itea virginica* (sweet spire), and *Smilax rotundifolia* (greenbriar). Characteristic ground layer species are *Onoclea sensibilis* (sensitive fern), *Impatiens capensis* (spotted jewelweed), *Polygonum* spp. (knotweeds), and *Carex* spp. (sedges). Historical records exist for several rare plant species in the area including the state extirpated *Najas gracillima* (thread-like naiad), state extirpated *Ranunculus hederaceus* (long-stalked crowfoot), state endangered *Gratiola viscidula* (short's hedge-hyssop), state rare/watch list *Carex hyalinolepis* (shoreline sedge), and the uncertain state status *Vitis cenerea* (graybark). Unconfirmed records also exist for the *Sagittaria calycina* (spongy lophotocarpus), a state rare species on the Jug Bay rare plant species list. Surveys for these species have not been conducted recently, and a thorough effort may reveal that several persist.

Permanent plots were established in 1987 in five forest habitats, including forested swamps to study succession, climate change, and the impact of invasive species at Jug Bay. Aerial photographs were used to map the habitat distribution with plots randomly located within the habitats. Burke and Swarth (1997) found 17 woody species, mostly shrubs, in the swamp forest habitat. The most numerous woody species were *Cornus amomum, Viburnum dentatum, Itea virginica*, and *Fraxinus pennsylvanica*. These species are native to the region and serve as excellent sources of cover and food for wildlife. The permanent plot study is ongoing.

3.4.1.7. Other estuarine habitats

Palustrine system

The palustrine system consists of non-tidal, perennial wetlands. Most of these habitats occur on the floodplains of the various waterways. These wetlands are characterized by emergent vegetation. This system includes wetlands that are permanently saturated by below-ground seepage, those that are permanently flooded as well as wetlands that are seasonally or intermittently flooded. Wetlands are a distinct habitat that can be identified by three characteristics: plant communities composed of hydrophytes, hydric soils (soils that lack dissolved oxygen), and by a hydrologic regime that involves some frequency of flooding.

Shrub swamp wetlands dominated by tall shrubs occur along the shores of some river and creek areas devoid of tidal flooding. They occur in wet depressions or in transition zones between marsh and swamp or upland communities. Characteristic shrubs include *Viburnum dentatum* (arrowwood), *Vaccinium corymbosum* (highbush blueberry), *Cornus foemina* (gray dogwood), *Spirea alba* (meadow-sweet), *Alnus serrulata* (smooth alder), *Lindera benzoin* (spicebush), *Rhodendendron viscosum* (swamp azalea), and *Salix nigra* (willow). The shrub swamp wetlands are prime habitat for the state rare and threatened *Chelone obliqua* (red turtlehead).

Seepage swamps contain larger shrubs and trees as compared to shrub swamp wetlands. Seepage swamps are extensive networks of seeps and shallow braided streams on gently sloping wooded terrain. Characteristic plants in seepage swamp habitat include *Osmunda cinnamomea* (cinnamon fern), *Veratrum viride* (false hellebore), *Viola cucullata* (marsh blue violet), *Viburnum nudum* (possum haw), *Symplocarpus foetidus* (skunk cabbage), and *Alnus serrulata* (smooth alder).

Seeps are small wetland areas fed by springs or headwaters of streams that can be geographically flat or can occur on low-grade slopes. Seeps contain few or no trees. Characteristic plants found in these wet places include *Chrysoplenium americanum* (golden saxifrage), *Cardamine pensylvanica* (Pennsylvania bittercress), and *Ranunculus spetentrionalis* (swamp buttercup).

Bottomland forests are characterized by their flood regime; low areas are flooded annually in spring, and high areas are flooded only irregularly. These woods occur in low-lying areas where the land is flat and moist. They are found on floodplains along streams or rivers that seasonally spill over with heavy rains, depositing rich alluvial soils. The trees in this habitat have adapted to changing levels of soil moisture and the roots can tolerate submergence in water for long periods of time. The characteristic trees found in the bottomland forests are predominantly deciduous hardwoods and include *Fraxinus pensylvanica* (green ash), *Acer rubrum* (red maple), *Platanus occidentalis* (sycamore), and *Liriodendron tulipfera* (tulip tree). Common shrubs include *Cornus spp*. (dogwoods), *Carpinus carolinianus* (ironwood), *Lindera benzoin* (spicebush), and *Viburnum* spp. (viburnums). Vines include *Toxicodendron radicans* (poison ivy), *Parthenocissus quinquefolia* (Virginia creeper), and *Vitis* spp. (wild grapes). Common herbaceous species include *Impatiens capensis* (jewelweed) and *Onoclea sensibilis* (sensitive fern). Invasive exotic herbs may be present including *Microstegium vimineum* (Asian stiltgass) and *Alliaria petiolata* (garlic mustard).

Lacustrine System

The lacustrine system consists of areas of non-flowing, long-standing waters that are not affected by tides. Ponds are located in depressions or in dammed stream channels. They often have persistent emergent vegetation along the pond edge and submerged or floating-leaved aquatic vegetation may grow in areas where sufficient sunlight penetrates the forest canopy.

Eutrophic ponds are small, shallow and are over-enriched in nutrients. The water is often green due to algal growth and bottom sediments are soft and mucky. Species diversity is typically high. Littoral and epilimnion species assemblages usually predominate. Characteristic plants include *Cladophora* spp. (algae), *Lemna* spp. (duckweeds), *Azolla caroliniana* (mosquito-fern), *Potamogeton* spp. (pondweeds), *Elodea Canadensis* (waterweed). *Alnus serrulata* (alder), *Acer rubrum* (red maple), *Viburnum dentatum* (viburnum), are also found growing at the edge of these ponds.

Quarry ponds are created or maintained by humans, or they are modified by human activity. Several old borrow pits are found adjacent to the upper railroad bed trail in the Jug Bay Wetlands Sanctuary. These ponds hold water most of the year, but may be almost dry during drought periods. Most quarry ponds have no outlet. The sides of the ponds are often steep so there is little shallow shoreline habitat available for plants. Water levels usually fluctuate markedly as a result of recent precipitation.

3.4.1.8 Marsh Functioning

Freshwater tidal marshes function in nutrient cycling, sediment capture, and as an important component in the food web. Much research has been done at Jug Bay and surrounding marshes on these topics, and we will focus on these studies in this section. For a general overview of marsh functioning, the reader is referred to section 2.4.1.8.

Tidal marshes have an important role in removing nutrients from the water before it travels downstream. Water overloaded with nitrogen and phosphorus causes blooms of phytoplankton that create anoxic conditions deleterious to animal and submerged plant life in the water. By cleansing the nutrients from the water, the freshwater tidal marshes of Jug Bay create a healthier environment downstream in the Chesapeake Bay. Fertilizers from farmland and residential areas enter the waterways through run-off during rain events. Highly eutrophic water enters the marsh system through groundwater and shallow streams and is slowed due to the low topography and tidal influx. During the hide tide portion of the tidal cycle, water levels rise and flood lower elevations of the marsh, depositing sediments and providing nutrients that are absorbed into the soil or consumed by microbes. Garcia et al. (1997) found restored *Phragmites* marshes to be nearly 100% efficient at removing nitrogen input into the system during the height of the growing season. Boumans et al. (2003) studied the effect of the freshwater tidal marsh system at Jug Bay as well as ten other sites and determined that water quality improved after flowing through the marsh. Studying Delaware River freshwater tidal marshes, Whigham and Simpson (1976) found that the high marsh acts as a nutrient sink during the summer months when productivity is high. In a marsh with a healthy component of plants and microbes, the nutrients are consumed quickly and the demand remains high, creating a nutrient sink. Khan and Brush (1994) found higher amounts of nutrients and pollutants from wastewater and agricultural chemicals in the high marsh than in the low marsh.

Neubauer et al. (2005) studied carbon cycling and greenhouse gas production comparing the tidal freshwater marshes of Jug Bay to brackish marshes further downstream on the Patuxent. They found less organic carbon in the soil and more microbial respiration in the soils of the freshwater marsh. By analyzing seasonal data, they found that plants mediated microbial metabolic pathways associated with the creation of methane and the reduction of iron. Methane is a gas produced by methanogenic bacteria present in wetland soils. There is debate about how much the emission of methane offsets the sequestration of carbon in wetland soils, although there is general agreement that the buildup of carbon in vegetation via photosynthesis and in soils via sediment and litter accumulation is an important sink.

The marshes of the Patuxent and its tributaries help to reduce the amount of sediment carried in surface waters by slowing the flow of the water and allowing settling of the sediment. Sediments suspended in the water reduce water quality by obscuring light to submerged vegetation. As with nutrients, sediments are mainly deposited during high tide when the water reverses its downstream movement. Pasternak and Brush (2001) found that both the time of the year and habitat type affected sedimentation and erosion in freshwater tidal marshes on the Bush River. Sedimentation was highest during the height of the growing season in the floating leaf (low marsh habitat). The low marsh accumulated the most sediment per year, while the high marsh lost more sediment than it accumulated in a given year.

The hydrology of the marsh plays an important role in the efficiency of nutrient and sediment removal. Phemister (2004) studied the importance of the source of groundwater for determining nutrient and sediment removal in the tidal marsh of Jug Bay Wetlands Sanctuary. She found that nutrient and sediment deposition is greater in areas of the marsh where the main source of incoming water is tidal flooding. In this situation, the soils absorb the nutrients and sediments as the water filters through and/or is removed via evapotranspiration. However, if the main source of marsh groundwater is an upland aquifer, the tidal water will be less likely to infiltrate the already-saturated soil, leaving a greater amount of nutrients in the water as it flows back out to the stream channel.

3.4.2 Upland Vegetation Community

3.4.2.1 Upland forest

The terrestrial forest habitats at Jug Bay are characterized by well-drained soils that are dry to mesic and vegetative cover that is predominantly mesophytic woody tree species. Hydrophytic vegetation is not prevalent in these systems although the soil surface in some areas is occasionally or seasonally flooded. All forest habitat that is not swamp, riparian, or bottomland is considered upland forest. A very comprehensive list of upland species found at Jug Bay and can be found in the Jug Bay Wetlands Sanctuary website at http://www.jugbay.org/research/species_lists.

The upland mixed hardwood forest is characterized as having more than 60% canopy cover of trees. A sparse, medium or dense understory of shrubs may occur. Habitats are well drained and dry. Areas of mature steady-state forest contain exclusively hardwood species. Characteristic deciduous hardwood trees include oaks such as *Quercus falcate* (red oak), *Quercus alba* (white oak), and *Quercus phellos* (willow oak); *Carya* spp. (hickories); *Fagus grandifolia* (American beech); *Tulipfera liriodendron* (tulip tree); *Acer rubrum* (red maple); *Liquidamber styraciflua* (sweet gum); and *Ilex opaca* (holly). Forest areas transitioning from pine forest to hardwoods contain representative evergreens including Eastern *Juniperus virginiana* (red cedar), *Pinus virginiana* (Virginia pine), and *Pinus taeda* (loblolly pine).

The upland pine forest is dominated by conifers that characteristically grow faster than most hardwoods. Coastal plain forests go through a process of forest growth from old field to pine forest to hardwood forest. The upland pine forest exists as a transition stage forest, occurring after the old field stage and before the forest is overtaken by hardwoods. This habitat is well drained and dry, and *Pinus virginiana* (Virginia pine) is most common with *Pinus taeda* (loblolly pines) occurring in scattered locations.

3.4.2.2 Vernal pools

Vernal pools are natural ponds that form in small, shallow depressions. They are ephemeral, flooding in spring or after a heavy rainfall and are usually dry during summer. Vernal pools may fill again in the autumn. They are most commonly found in bottomland forests but can be in other areas. They typically occupy a closed basin with no outflow. Under flooding conditions, an intermittent stream may drain them. The substrate is typically dense leaf litter over hydric (oxygen-poor) soils. Vernal pools are important because they provide a unique habitat for amphibians, invertebrates, and turtles. The plants of vernal pools are predominantly hydrophytic with both obligate and facultative species. Floating and submerged plants may be common but emergent plants are usually sparse or lacking. Characteristic vascular plants include *Eleocharis acicularis* (spikerush), *Ludwigia palustris* (water purslane), and *Najas* spp. (naiad). *Acer rubrum* (red maple), *Nyssa sylvatica* (sourgum), and *Vaccinium* spp. may border the pool.

Vernal pools at Jug Bay support a diverse community of amphibians, invertebrates, and reptiles (Swarth 2003). Frog species including *Rana sylvatica* (wood frogs) lay their eggs in the water in spring. In the fall, marbled salamanders migrate by the hundreds to the vernal pools to mate and lay their eggs.

A vernal pool study was started in 2000 in the Jug Bay Glendening Preserve to monitor the populations of plant and animal species and keep track of the physical properties of the pools. Numbers of egg masses of frogs and salamanders are recorded, and larvae are caught by dip netting and counted. Physical characteristics such as weather conditions, wind, water quality (dissolved oxygen, conductivity, salinity, water temperature, pH, nutrients, secchi depth, and total depth), air temperature, and soil temperature are recorded. By collecting this data, estimates of populations can be made and physical and species data can be compared from year to year.

3.4.2.3 Other upland habitats

There are six other distinctive upland habitats at Jug Bay. These habitats are all considered open habitats that lack tree cover. One habitat remains open due to poor growing conditions for vegetation, with the remaining five maintained as open habitats.

An excavation site for old sand mines occurs in the northwest corner of the Jug Bay Wetlands Sanctuary on the Wade property. The open habitat resulting from the creation of the sand mines is exposed deep sandy soils. Droege et al. (2009) found a unique flora and fauna associated with this "micro-desert" habitat. The community occurs as a remnant patch with rare species of plants and insects (beetles and bees) restricted to the habitat whose closest populations are sometimes hundreds of kilometers away. Droege et al. (2009) impress the importance of conservation of this area and stress that, in the absence of rare vertebrate species, a combination of plant and insect inventories is needed to clarify a site's importance.

Old field habitat – a meadow with shrub patches – is found in several areas. Old fields are abandoned open lands that were cleared of trees and were once in constant use for cultivation and pasture. Over time they have undergone succession from field to shrub to tree-dominated communities. Old field habitat near the Jug Bay Wetlands Sanctuary visitor center is prevented from progression to demonstrate this successional community. Characteristic shrubs include *Rhus copallina* (winged sumac), *Sassafras albidum* (sassafras), and *Toxicodendron radicans* (poison ivy). Herbs include *Solidago* spp. (goldenrods), *Oenothera biennis* (common evening primrose), *Daucus corota* (Queen-Anne's lace), *Ambrosia artemisiifolia* (ragweed) and *Actinomeris alternifolia* (wingstem).

Managed meadows are open places that are free from encroaching woody vegetation, either because they are deliberately burned or mowed, or because they have thin, nutrient-deficient soils. Native and non-native herbaceous plants and grasses dominate these habitats. At Jug Bay, several meadows are specifically managed for wildlife. Characteristic plants include *Andropogon gerardi* (big bluestem), *Andropogon scoparius* (little blue stem), *Asclepias* spp. (milkweeds), *Solidago* spp. (goldenrod), *Ambrosia artemisiifolia* (ragweed), *Opunta humifusa* (prickly pear), and *Monarda punctata* (horsemint).

Vegetable, crop plant, flower and herb gardens at Jug Bay include the cultivated lands at Aquasco Farm, the South County Community Garden at River Farm and the old native plant garden near the Jug Bay Wetlands Sanctuary center. These gardens were created specifically for the production of crops, vegetables, and herbs and for the display of individual representative native plants. Aquasco Farm agriculture demonstrates sustainable farming practices.

An abandoned railroad bed runs for about 1.5 miles through the sanctuary dividing the marsh into the north Glebe marsh and the south Glebe marsh. The addition of fill materials into the marsh to create the track bed caused a shift in vegetation to open upland habitat along the length of the track bed. It is characterized by hard packed, well-drained soil which was built up expressly for the need for a solid, unmovable sub-surface. The surface consists largely of small metallic pebbles ("clinkers") which are the unburned residue from the coal that was used as engine fuel. Common flowers along the edge of the bed include *Arabis lyrata* (lyre-leaved rockcress) and *Lepidium virginicum* (wild peppergrass).

The Jug Bay component contains a small amount of land that has been cleared by lawn mower or by brush-hog. Examples include the lawn and other open areas around the Jug Bay Wetlands Sanctuary center, areas around the outdoor exhibits at Patuxent River Park, and near the barns and houses at the Reserve and the River Farm. Several cleared areas also occur along some hiking trails. Wiregrass dominates most of the lawn areas.

3.4.3 Microbiological Components

Microbial activity within marsh sediment is necessary for material and nutrient cycling within an estuary. Microbes are crucial for nitrogen cycling. In the soil, both aerobic and anaerobic bacteria decompose dead plant material or detritus resulting from plant production. Vascular plant detritus is rich in indigestible fibers such as lignin or cellulous. Microbes have the ability to turn the indigestible fibers into digestible carbohydrates for detritus feeders (Mann 2000). The breakdown of dead plant material by microbes is also a key contributor to the accumulation of organic matter and the build-up of marsh surfaces in estuarine environments. In deeper portions of the marsh, anaerobic bacteria break down organic matter into ammonium, hydrogen sulfide, methane, and other products.

Some bacteria cause disease in humans and are classified as pathogenic bacteria. In estuarine environments, shellfish are vectors for human disease and other pathogens because pathogenic bacteria living in the water column are filtered through shellfish tissues. Pathogenic bacteria result from human and animal feces; therefore, it is necessary to monitor fecal pollution sources in shoreline areas where shellfish are grown and harvested due to the public health risks associated with the consumption of contaminated shellfish. Microbial contamination is closely related to population growth and development, rainfall events, storm water runoff, and river flows. Fecal coliform bacteria are used as indicator organisms to quantify the presence of pathogenic bacteria. Fecal coliform bacteria enter rivers through direct discharge of waste from point and non-point sources, including: agricultural and storm runoff, mammal and bird feces, and human sewage (Glasoe and Christy 2004). In the late 1990s and early 2000s, specific water quality regulations were established through total maximum daily loads (TMDLs) due to contamination by nutrients and sediments, including fecal coliform bacteria. As a result, many creeks in the Lower Patuxent River Basin on the western and southwestern shoreline of the Patuxent River are restricted shellfish harvesting waters (MDE 2005).

During the summer of 2010, the Calvert County Health Department posted advisories for the presence of the bacteria, *Vibrio vulnificus*, at public beaches and boat ramps near Broome's Island. As of mid-August, 24 *Vibrio* infections were reported while 30 infections are reported on average each year (Broom 2010). The presence of non-cholera, *Vibrio*, infections have increased in recent years due to the combination of increased water temperatures and salinity. Most infections are associated with the consumption of contaminated shellfish or from the exposure of open skin to warm salt water (Calvert County Health Department 2010).

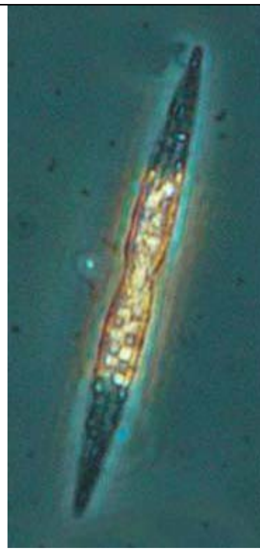
3.4.4 Plankton

3.4.4.1 Phytoplankton

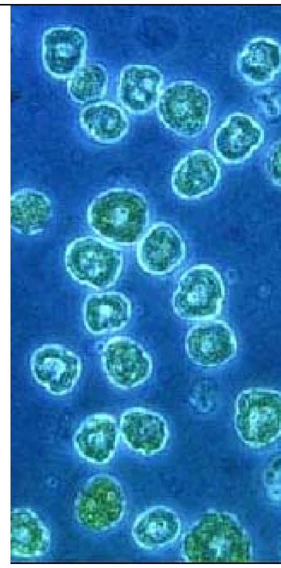
Phytoplankton are microscopic, free-floating primary producers in aquatic systems and are the basis of most aquatic food chains. They are a major food source to many organisms which in turn are prey to organisms of higher trophic levels. Phytoplankton communities are structured by salinity, temperature, light, and nutrient availability. Excess nutrients and light in an aquatic system provide favorable growth conditions for phytoplankton; rapid increases in phytoplankton abundance result in algal blooms (Jug Bay Wetlands Sanctuary 2010). Several species, if found in high concentrations, are toxic and cause serious health issues.

Little information was known about phytoplankton species specific to the Jug Bay area prior to the 2007 Jug Bay Wetlands Sanctuary Bioblitz of 2007 (Swarth et al. 2008). During the

BioBlitz, plankton was collected at the River Pier for three hours by staff and volunteers. Representatives of the Bacillariophyta (diatoms) and Dinoflagellata (dinoflagellate) phytoplankton groups were observed, specifically *Nitzchia* spp. and *Gymnodinium* spp. (Figure 3.4.15).



Nitzchia hungarica



***Gymnodinium* spp.**

Photo credit: Smithsonian Environmental Research Center Phytoplankton Guide.

Figure 3.4.15 Phytoplankton species observed during the Jug Bay Wetlands Sanctuary Bioblitz of 2007.

In 2001, NOAA designated a volunteer monitoring program called the Phytoplankton Monitoring Network to increase public awareness of local waters. The Jug Bay Wetlands Sanctuary became involved with the program in 2009. Data collected for this monitoring effort are focused more on qualitative information, rather than quantitative, as exact volumes of water are not quantified. The objectives of the monitoring effort are to understand the changes in the phytoplankton community throughout the year as light and temperature values shift. Phytoplankton communities were sampled from the Jug Bay Railroad Bridge (38.78127, -76.71368) twice a month beginning in August of 2009. Since 2009, 26 known genera have been found off of the Jug Bay Railroad Bridge sampling site (Table 3.4.2). To become involved in the Phytoplankton Monitoring efforts at Jug Bay Wetlands Sanctuary, visit the Jug Bay website at www.jugbay.org/volunteer.

Table 3.4.2 Representative phytoplankton genera found at the Jug Bay component, Jug Bay Railroad Bed sampling site (Unpublished data, courtesy of Kathy Ellett and Elaine Friebele).

Bacillariophyta (Diatoms)	**Chlorophyta (Green Algae)**	**Chrysophyta (Golden Algae)**	**Cyanobacteria (Blue-green Algae)**	**Dinoflagellata (Dinoflagellates)**
Bacillaria	*Actinastrum*	*Dinobryon*	*Anabaena*	*Ceratium*
Coscinodiscus	*Closterium*	*Mallomonas*	*Microcystis*	*Unknown dinoflagellate*
Cymbella	*Pandorina*			
Grammatophora	*Pediastrum*			
Guinardia	*Scenedesmus*			
Licmophora	*Selenastrum*			
Melosira	*Spirogyra*			
Navicula	*Volvox*			
Nitzschia				
Pleurosygna/ Gyrosigma				
Pinnularia				
Synedra				
Thallasotrix				

Bacillariophyta (diatoms) are the most well represented group at Jug Bay with 13 identified species followed by Chlorophyta (green algae) with eight identified species. Other groups include Chrysophyta (golden algae) and Cyanobacteria (formerly, the blue-green algae) with two species and Dinoflagellata (dinoflagellates). According to the data available through the Phytoplankton Monitoring Network (http://chesapeakebay.noaa.gov/community-generated-observations/phytoplankton-monitoring-network), *Bacillaria*, *Coscinodiscus*, *Melosira*, *Navicula* are found most frequently at Jug Bay (Figure 3.4.16.).

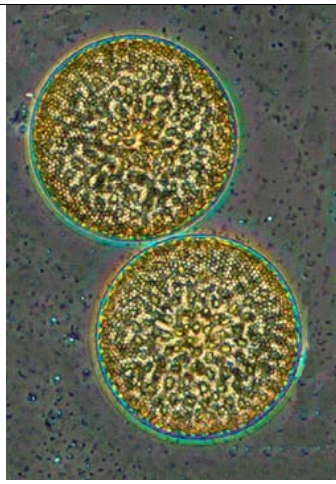
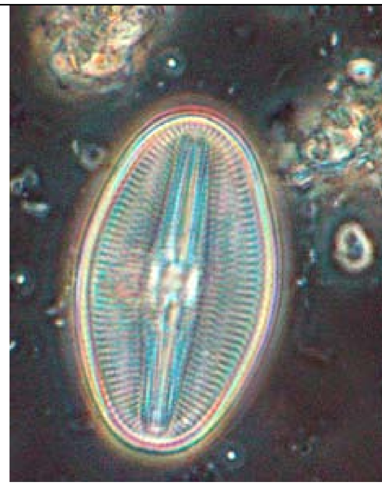
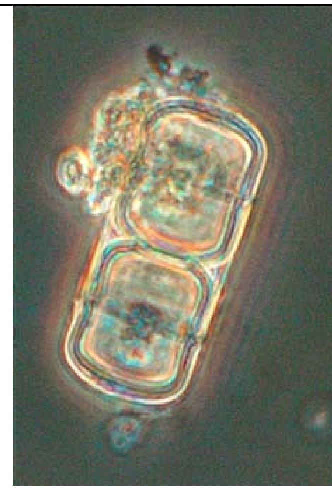
		
***Coscinodiscus* spp.**	***Navicula* spp.**	***Melosira varians***

Photo credit: Smithsonian Environmental Research Center Phytoplankton Guide.

Figure 3.4.16 Pictorial examples of the most common diatom species found at Jug Bay Railroad Bed. These photos are not from samples obtained from the Jug Bay Railroad Bed Station.

Some other monitoring efforts of the phytoplankton communities within the Chesapeake Bay and tidal tributaries are those conducted by the Chesapeake Bay Program and the Maryland Department of Natural Resources. Numerous stations around the state have been sampled since 1995. Data and additional information regarding these programs can be accessed at: http://www.chesapeakebay.net/data_plankton.aspx and http://www.dnr.state.md.us/bay/monitoring/phyto/index.html, respectively.

There are no monitoring stations within the Jug Bay Reserve; however, there are stations located downstream in the Patuxent River. The Nottingham station (38.71012 -76.7014) is located in the mid-channel of the Patuxent and is characterized as oligohaline (Figure 3.4.17).

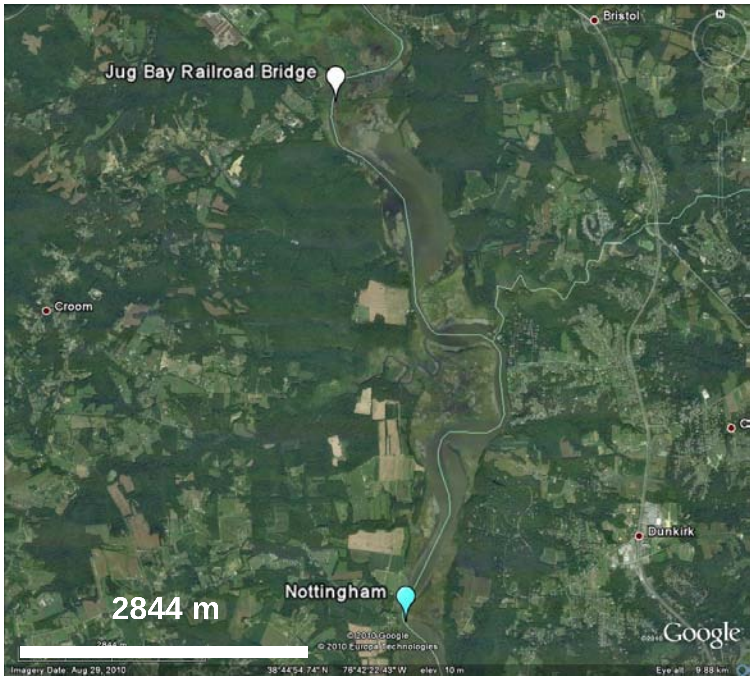


Figure 3.4.17 Map showing the Jug Bay River Pier (white) and Nottingham (light blue) plankton monitoring sites.

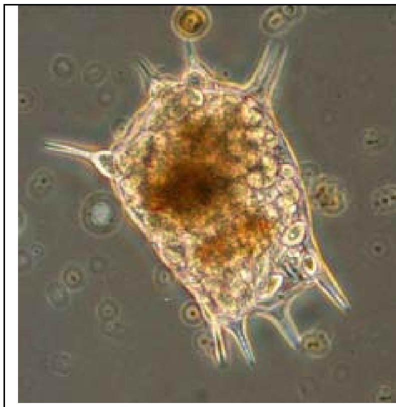
From 1995 to 2002, the phytoplankton community at Nottingham was dominated by diatoms with the occasional presence of cyanobacteria and pigmented flagellates. From 2003 to 2011 (present), data collection, analysis, and interpretation was graphed as family presence rather than common name. Therefore, from 2003 to 2011, bacillariophyceae (diatoms) are the most abundant, similarly to 1995 through 2002. Furthermore, unidentified flagellates and chlorophyceae are occasionally present. Cyanophyaceae were found from 2006 through 2011 (http://www.dnr.state.md.us/bay/monitoring/phyto/data/pxt.html).

3.4.4.2 Zooplankton

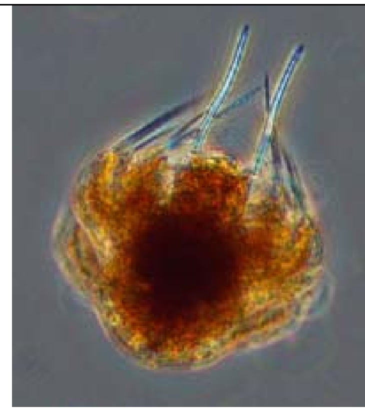
Zooplankton are a diverse group of small aquatic invertebrates, which are typically heterotrophic and sometimes detritivorous. Holoplankton spend their entire life cycle as plankton and act as the middle step between trophic levels. Holoplankton prey upon phytoplankton and bacteria at the bottom of the food chain; they in turn are preyed upon by species at higher trophic levels, such as fish and their larvae (Mann 2000). Commercially important species of oysters, clams, and crabs are also included within the zooplankton community because they spend a portion of their life cycle in free-floating larval stages and are called meroplankton.

Zooplankton communities were quantified at the 2007 Jug Bay Wetlands Sanctuary BioBlitz. Representatives of three different groups of zooplankton, including rotifers, crustaceans, and protozoa, were collected at the Jug Bay River Pier (Kathy Ellett personal observation; Swarth et al. 2008).   Species found were *Brachionus* spp., copepod and flagellate species (Figure 3.4.18).

Through plankton research done by staff and volunteers from the sanctuary, a total of 30 known species of zooplankton have been identified (Table 3.4.3).



Brachionus calyciflorus



Copepod nauplii

Photo credit: Smithsonian Environmental Research Center Phytoplankton Guide.

Figure 3.4.18 Zooplankton species observed during the Jug Bay Wetlands Sanctuary Bioblitz of 2007 (Swarth et al. 2008).

Table 3.4.3 Zooplankton found in the tidal Patuxent River at Jug Bay (Source: www.jugbay.org).

Rotifers	Protozoa	Others
Ascomorpha	*Arcella*	*Cyclopoid nauplii*
Anuraeopsis	*Codenella*	Copepod
Asplanchna	*Codonellopsis*	Cladocera
Brachionus	*Difflugia*	Tartigrada
Euclanis	*Euplotes*	Nematode
Filinia	*Helizoa*	Ostracoda
Hexarthra	Hypotrich	
Kellicottia	Tintinnids	
Keratella	*Unknown*	
Lanicularia flosculosa		
Lecane		
Monostyla		
Notholca		
Polyarthra		
Synchaeta		
Trichocera		
Unknown		

The Chesapeake Bay Program and the Maryland Department of Natural Resources (Maryland DNR) monitor the zooplankton communities within the Chesapeake Bay and tidal tributaries. Maryland DNR established twelve study sites in 1985 within the Choptank, Potomac and Patuxent Rivers. Currently, there are four sampling stations located in the Patuxent River, all south of the Reserve (Figure 3.4.19). Data analyzed from 1985 through 2000 yielded an annual increase in zooplankton density in the upper Patuxent River. Furthermore, zooplankton serve as food sources for larval striped bass and optimal levels of zooplankton were observed in the Patuxent River beginning in 1994 (Maryland DNR 2002).

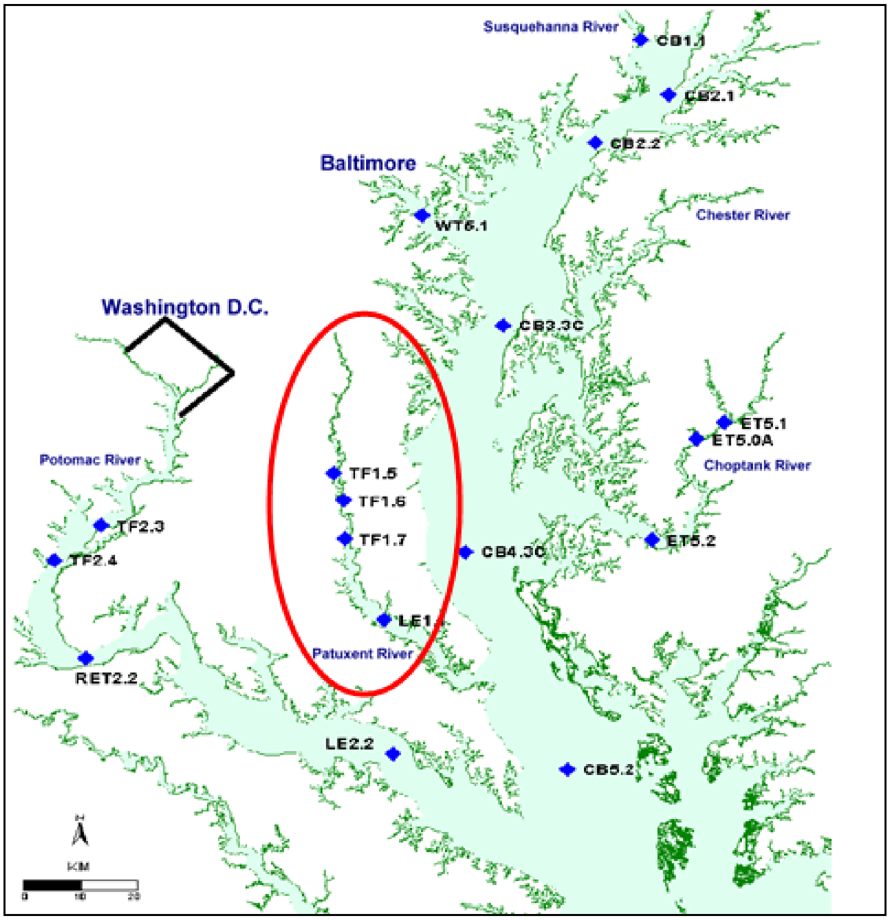


Figure 3.4.19 Map of the Maryland Department of Natural Resources zooplankton monitoring stations. A red elipse encircles the four stations located in the Patuxent River. Map source: http://www.dnr.state.md.us/bay/monitoring/zoop/map.html.

3.4.5 Benthic Macroinvertebrates

The benthic macroinvertebrate community of Jug Bay streams has been studied by volunteers and professionals. The Jug Bay Wetlands Sanctuary (JBWS) has a volunteer-based macroinvertebrate sampling program under their Watershed Stream Study. The program was established in 2009 to monitor three streams (Galloway Creek, Two Run Branch, and Pindell

Branch) that flow through JBWS to the Patuxent River. Several times throughout the year, volunteers and staff collect in the field and identify macroinvertebrates in the laboratory.

The JBWS and Patuxent River Park (PRP) held a Bioblitz in 2007 and 2009, respectively. A Bioblitz is a continuous 24 hour plant and animal survey and inventory guided by professionals. Jug Bay Wetlands Santuary reported species of five earthworms and three species of isopods. Patuxent River Park reported nine species of earthworms, four isopods, and 21 odonata among many other organisms recorded that day. Their combined Bioblitz findings of macroinvertebrates are displayed in Table 3.4.4.

Table 3.4.4 Partial species list of macroinvertebrate fauna collected during the 2007 Jug Bay Wetlands Sanctuary and 2009 Patuxent River Park Bioblitzes. Information source: Patuxent River Park Bioblitz 2009 report, Jug Bay Wetlands Sanctuary Bioblitz 2007 report.

Phylum	Family	Species	Common Names
Annelida	Lumbricidae	*Amynthas hilgendorfi*	Asian earthworm
		Aporrectodea caliginosa	Grey worm
		Bimastos tumidus	European nightcrawler
		Dendrobaena octaedra	Octagonal-tail worm
		Dipolcardia patuxentis	
		Eisenia fetida [foetida]	Redworm
		Eisenoides lönnbergi	
		Lumbricus rubellus	Red earthworm
		Lumbricus terrestris	Nightcrawler
		Octolasion lacteum	
	Megascolecidae	*Amynthas corticus*	
Arthropoda	Asellidae		Sow bugs
	Gammaridae		Scuds
	Calopterygidae		Broad-winged damselflies
	Cordulegastridae		Spiketails
	Gomphidae		Clubtail dragonflies
	Capniidae		Small winter stonefly
	Corydalidae		Dobson flies/fish flies
	Sialidae		Alderflies
	Elmidae		Riffle beetles
	Gyrinidae		Whirlygig beetles
	Haliplidae		Crawling water beetles
	Scirtidae		Marsh beetles
	Limnephilidae		Northern caddisflies
	Leptoceridae		Long-horn caddisflies
	Ceratopogonidae		Biting midge
	Chironomidae		Non-biting midges
	Tipulidae		Crane flies

The Maryland DNR, Maryland Biological Stream Survey (MBSS) has also studied the local streams. The main objectives of this study (Stranko et al. 2007) were to (1) characterize the ecological condition of the major tributary sub-watersheds that feed into Jug Bay; (2) identify likely sources and locations of stressors to streams in the area; and (3) examine the efficacy of restoration work conducted in non-tidal portions of the watershed.

Stream ecological condition, as measured by fish and benthic macroinvertebrate index of biotic integrity (IBI) scores, ranged from 1.0 (the lowest possible score) to 5.0 (the highest possible score) at all nontidal sites. High ecological conditions, based on good IBI scores (>4.0) for fish or macroinvertebrates, were observed in 14 streams. Fifteen streams had low biological integrity, based on poor IBI scores (<3.0) for fish or benthic macroinvertebrates. Many streams had both poor and good conditions in different sections of the same stream or had poor scores for one biological indicator (e.g. the fish Index of Biotic Integrity) and good scores for the other indicator (Stranko et al., 2007). Benthic IBI scores for sites sampled in tributaries to the Jug Bay component of CBNERR-MD were taken from Stranko et al. (2007; Figure 3.4.20).

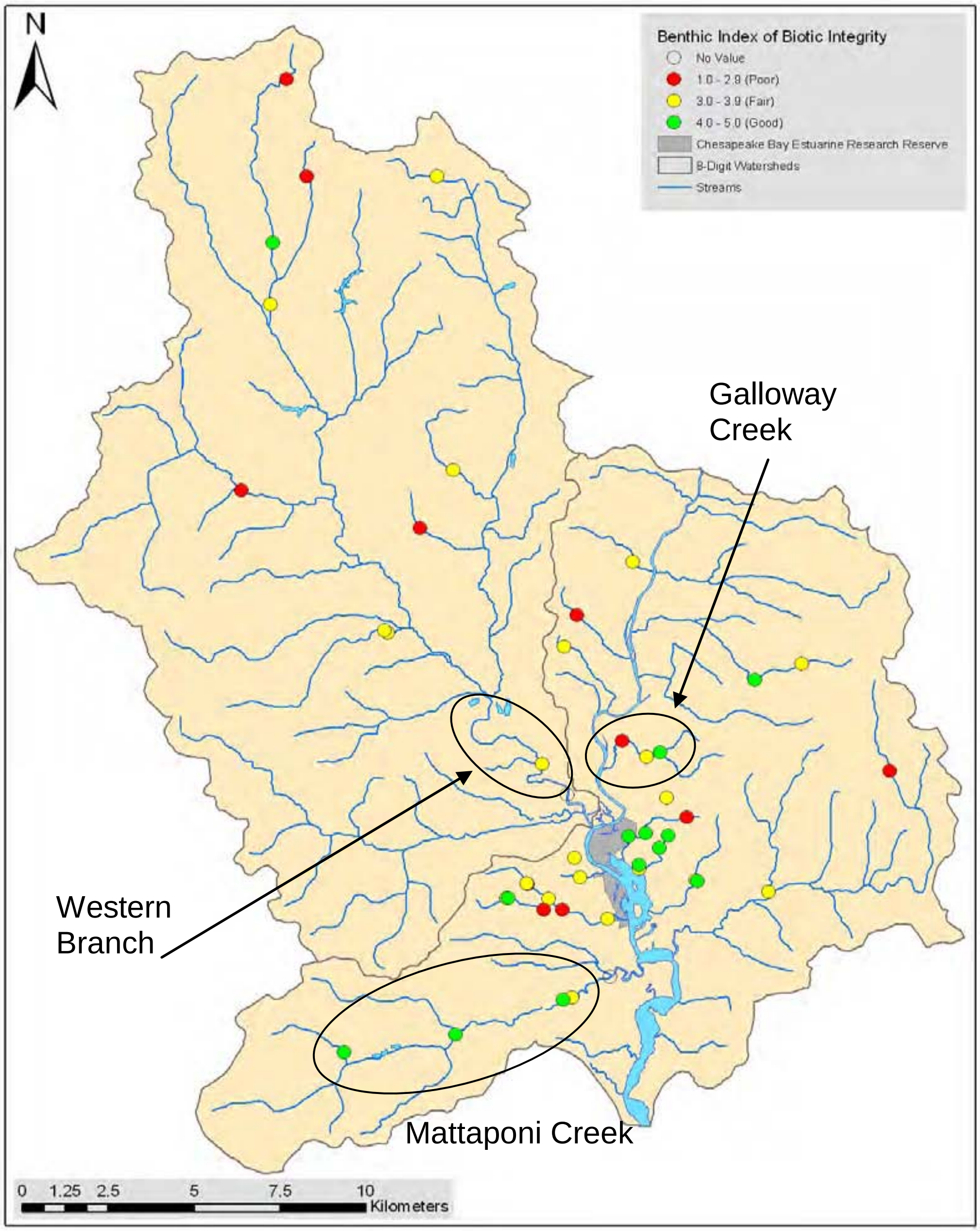


Figure 3.4.20 Benthic Index of Biotic Integrity scores for sites sampled in tributaries to the Jug Bay Reserve component. Highlighted are the sites for Mattaponi Creek, Western Branch and Galloway Creek. Source: Stranko et al. (2007).

Overall, no significant differences in macroinvertebrates were evident between "in" and "out" sites ("in" and "out" are sites within and outside the boundaries of the Jug Bay component for the catchment of three streams: Two-Run Branch, Pindell Branch, and Swan Point Creek). Benthic macroinvertebrate taxa richness, a simple measure of diversity and one of the metrics used to calculate the BIBI, was comparable for "in" and "out" sites combined and along each stream (Figure 3.4.21; mean for "in" and "out" sites was 23 and 25, respectively). "In" sites were dominated by chironomid (non-biting midge) larvae in the genera Microspectra, Tanytarsus, and Orthocladius. Chironomids are, as a group, tolerant to pollution. Freshwater clams in the family Sphaeridae, and oligocheate worms in the family Tubificidae were also dominant among the “in” sites. “Out” sites were dominated by chironomid genera such as Chaetocladius, Tanytarsus, Microspectra, and Orthocladius. Two of the “out” sites - the unnamed tributary to the south on Swan Point Creek (PAXM-112-X-2006) and Mataponi Creek (PAXM-221-X-2006) – were dominated by stoneflies in the genera Isoperla and Amphinemura, respectively. Stoneflies, as a group, are typically pollution sensitive. Fewer stonefly taxa and individuals were found among “in” sites relative to “out” sites. These findings suggest that the benthic macroinvertebrate communities of “out” sites may be slightly less ecologically impaired than “in” sites and likely reflect conditions that result from relatively acidic, highly embedded streams found in the Reserve area and less acidic, less embedded streams found upstream, and outside the resource area.

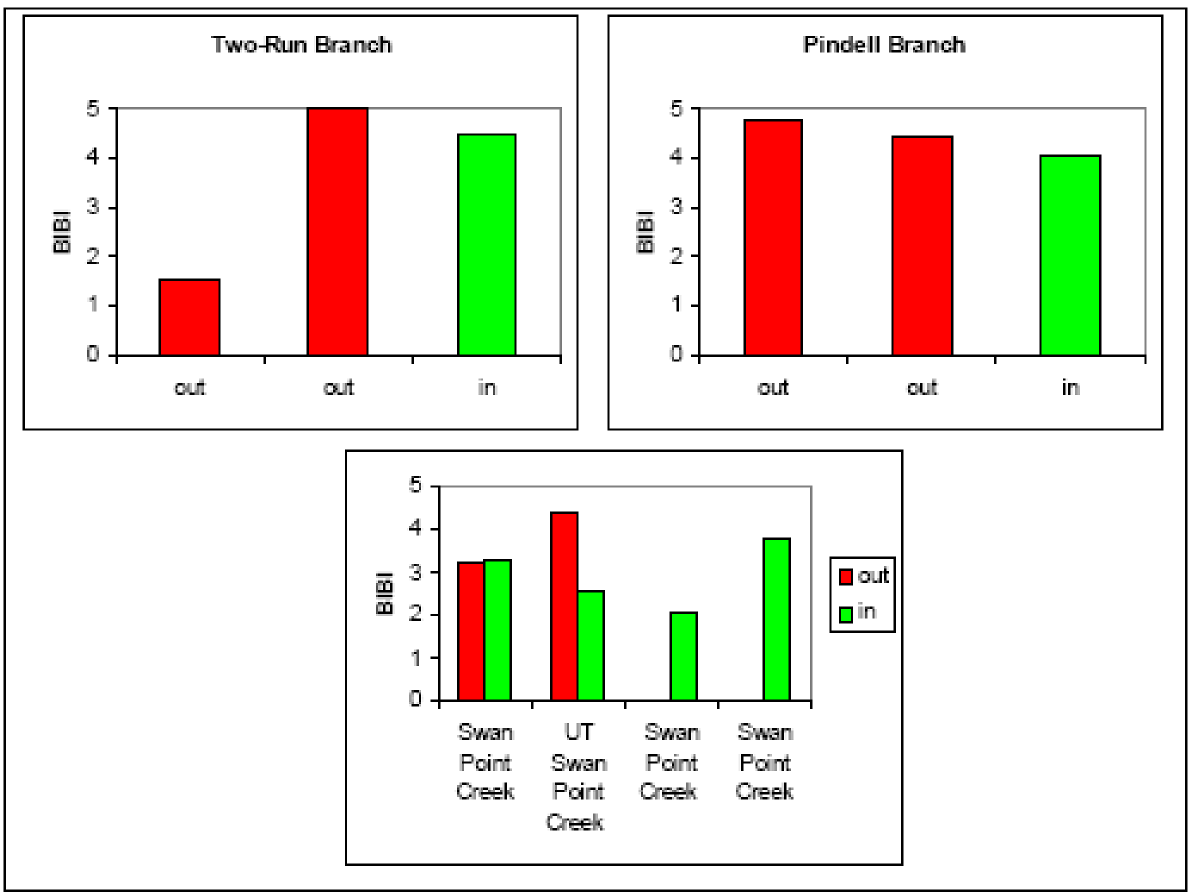


Figure 3.4.21 Macroinvertebrate Index of Biotic Integrity scores in the catchments of sites “in” and “outside” the Jug Bay CBNERR-MD component for three streams. Source: Stranko et al. (2007).

3.4.6 Fish, Reptiles, and Amphibians

3.4.6.1 Fish

Many fish use the waters and wetlands at Jug Bay for spawning, feeding, and shelter. The various wetland locations and low salinity make this area a very habitable environment. Important and diverse habitats include the shallow, sloping tidal shoreline that is vegetated in some areas and devoid of vegetation in others; the non-tidal creeks with riffles and pools that are shaded or in the open sun; permanent and temporary ponds with areas of deep and shallow water; and deep channel open water areas. When the tide is high, fish have access to a great expanse of flooded mudflats in the marsh. When the tide is low, the fish retreat to areas that are permanently flooded such as the open channels.

There are no known indicator fish species for tidal freshwater wetlands. Three categories make up the fish community in tidal freshwater systems: year-round freshwater residents, estuarine residents, and migratory species. Odum et al. (1984) reported that by far the largest group to occupy such areas is freshwater fish. The freshwater residents at Jug Bay include *Hybognathus regius* and *Pimephales promelas* (minnows), *Notemigonus crysoleucas* and *Notropis* spp. (shiners), *Enneacanthus gloriosus* (sunfish), *Pomoxis* spp. (crappies), and *Ictalurus punctatus* (catfish). Estuarine fish that live as year-round residents include *Fundulus diaphanous* (banded killifish), *Fundulus heteroclitus* (mummichogs), and *Trinectes maculates* (hogchokers).

Two types of migratory fish inhabit the waters of Jug Bay. Anadromous species spend the majority of their lives in the ocean and return to the freshwater and brackish environments of the bay and its tributaries each spring to spawn. Catadromous species, on the other hand, spend most of their life in the freshwater environment and return to the ocean to spawn. In these cases, the tidal freshwater wetlands are relied upon heavily for part of their life cycle (Mitsch and Gosselink 2000). *Alosa sapidissima* (American shad), *Morone saxatilis* (striped bass or rockfish), *Alosa pseudoharengus* (alewife), *Dorosoma cepedianum* (gizzard shad), and *Leiostomus xanthurus* (spot) are the anadromous fish inhabiting Jug Bay (Rodney 1990). *Anguilla rostrata* (American eel) is the one representative of catadromous species in the Jug Bay waters (Rodney 1990).

Forty five species of fish have been collected in the wetlands and open waters of the Jug Bay component. These represent 16 different families. The predominant species are *Fundulus heteroclitus* (mummichog), *Menidia beryllina* (inland silverside), *Alosa pseudoharengus* (alewife), *Fundulus diaphanous* (banded killifish), *Morone Americana* (white perch), *Notropis hudsonius* (spottail shiner), *Anchoa mitchilli* (bay anchovy), *Etheostoma olmstedi* (tesselated darter), *Notemigonus crysoleucas* (golden shiner), *Erimyzon oblongus* (creek chubsucker), *Lepomis macrochirus* (bluegill sunfish), *Cyprinella analostana* (satinfin shiner), and *Gambusia holbrooki* (mosquitofish). Table 3.4.5 lists the fish families and species present along with common names found at Jug Bay. Habitat data in Table 3.4.5 was collected over a 10-year period of fish surveys at JBWS (Molines and Swarth 1996). A comprehensive list of fish species found at Jug Bay can be found in the Jug Bay Wetlands Sanctuary website at http://www.jugbay.org/research/species_lists.

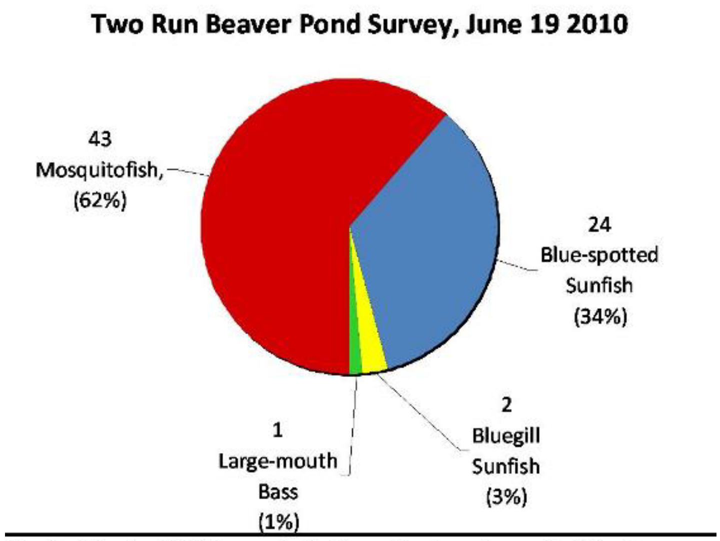
Table 3.4.5 Fish species found within the Jug Bay Wetlands Sanctuary and adjacent Patuxent River estuary. Species were classified in four categories: I = Introduced, T=Tidal, N=Non-tidal, A= Tidal and Non-tidal Habitats. Source: Molines and Swarth (1996).

Family	**Common Name**	**Scientific Name**	**Category**
Anguillidae	American eel	*Anguilla rostrata*	A
Atherinidae	Inland silverside	*Menidia beryllina*	A
Catostomidae	White sucker	*Catostomus commersoni*	N
Catostomidae	Creek chubsucker	*Erimyzon oblongus*	N
Centrarchidae	Bluespotted sunfish	*Enneacanthus gloriosus*	A
Centrarchidae	Pumpkinseed	*Lepomis gibbosus*	A
Centrarchidae	Bluegill	*Lepomis macrochirus*	I A
Centrarchidae	Smallmouth bass	*Micropterus dolomieu*	I
Centrarchidae	Largemouth bass	*Micropterus salmoides*	I T
Centrarchidae	White crappie	*Pomoxis annularis*	I
Centrarchidae	Black crappie	*Pomoxis nigromaculatus*	I T
Clupeidae	Alewife	*Alosa pseudoharengus*	T
Clupeidae	American shad	*Alosa sapidissima*	A
Clupeidae	Blueback herring	*Alosa aestivalis*	
Clupeidae	Hickory shad	*Alosa mediocris*	T
Clupeidae	Menhaden	*Brevoortia tyrannus*	
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	T
Cyprinidae	Goldfish	*Carassius auratus*	I
Cyprinidae	Rosyside dace	*Clinostomus funduloides*	N
Cyprinidae	Satinfin shiner	*Cyprinella analostana*	N
Cyprinidae	Common carp	*Cyprinus carpio*	I T
Cyprinidae	Eastern silvery minnow	*Hybognathus regius*	A
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*	A
Cyprinidae	Spottail shiner	*Notropis hudsonius*	A
Cyprinidae	Swallowtail shiner	*Notropis procne*	N
Cyprinidae	Fathead minnow	*Pimephales promelas*	I
Cyprinidae	Blacknose dace	*Rhinichthys atratulus*	N
Cyprinidae	Creek chub	*Semotilus atromaculatus*	N
Cyprinidae	Fallfish	*Semotilus corporalis*	N
Cyprinodontidae	Banded killifish	*Fundulus diaphanous*	T
Cyprinodontidae	Mummichog	*Fundulus heteroclitus*	A
Engraulidae	Bay anchovy	*Anchoa mitchilli*	T
Esocidae	Redfin pickerel	*Esox americanus*	N
Ictaluridae	Brown bullhead	*Ameiurus nebulosus*	A
Ictaluridae	Channel catfish	*Ictalurus punctatus*	I A
Moronidae	White perch	*Morone americana*	A
Moronidae	Striped bass	*Morone saxatilis*	T
Percidae	Tessellated darter	*Etheostoma olmstedi*	A
Percidae	Yellow perch	*Perca flavescens*	A
Petromyzontidae	Least brook lamprey	*Lampetra aepyptera*	N
Poeciliidae	Mosquitofish	*Gambusia holbrooki*	A
Sciaenidae	Spot	*Leiostomus xanthurus*	T
Soleidae	Hogchoker	*Trinectes maculates*	T
Umbridae	Eastern mudminnow	*Umbra pygmaea*	A

The first study of fish in the Patuxent River was conducted from 1948–1950 by Romeo Mansueti, a Master's student at the University of Maryland. Since then, much research has focused on the distribution and ecology of Patuxent River fishes. Studies by federal agencies such as Fish and Wildlife Service, National Fisheries Research Center, United States Geological Service, and Environmental Protection Agency; state agencies such as Department of Natural Resources and the University of Maryland Center for Environmental Science; academic institutions such as University of Maryland; county government agencies; and local programs at Jug Bay Wetlands Sanctuary (JBWS) and Patuxent River Park all have important information of the fish of this area.

The JBWS fish survey is a volunteer-led monitoring program that was created to study the fish of the tidal Patuxent River, the non-tidal creeks, and permanent and temporary ponds. Differences in fish species diversity and abundance are documented among the different habitats and throughout the years of the study. Age and size classes of fish are also recorded. The following activities are conducted during monitoring: fish are captured using seines and nets, fish are identified using keys and field guides, fish are measured, and fish are released. Data from the survey indicates that the most common species of the open waters of the Patuxent include *Fundulus heteroclitus* (mummichogs), *Fundulus diaphanous* (banded killifish), *Morone americana* (white perch), and *Notropis hudsonius* (spottail shiners). Some species are exclusive to the river waters including *Carassius auratus* (goldfish), *Pimephales promelas* (fathead minnows), *Alosa sapidissima* (American shad), *Alosa aestivalis* (blueback herring), *Leiostomus xanthurus* (spot), and *Pomoxis nigromaculatus* (black crappie). *Gambusia holbrooki* (mosquitofish), *Notemigonus crysoleucas* (golden shiner), *Enneacanthus gloriosus* (bluespotted sunfish), and *Ameiurus nebulosus* (brown bullhead) make up the majority of the species in the calm waters of Beaver pond. Several species are found principally in Pindell Creek and/or Two Run Creek including *Rhinichthys atratulus* (blacknose dace), *Clinostomus funduloides* (rosyside dace), *Erimyzon oblongus* (creek chub), *Esox americanus* (redfin pickerel), and *Semotilus corporalis* (fallfish). Habitat information for each species collected at Jug Bay over a 10-year period can be found in Table 3.4.5. A pictorial guide to fish identification was developed for Jug Bay using information from the fish survey (fish indentification key developed by Campbell and Molines).

During the 2010 survey of the Beaver Pond, a total of 70 fish were caught. Figure 3.4.22 shows the percentages of the four most common species caught that day. Bluegill sunfish, blue-spotted sunfish and mosquitofish are commonly found in both tidal and non-tidal waters.



Results of the June 19th fish survey in the Beaver Pond near the mouth of Two Run Branch. 70 individuals were caught, with relative abundance displayed above.

Figure 3.4.22 Two Run Beaver Pond Survey for 2010. Source: Jug Bay Wetlands Sanctuary: http://www.jugbay.org/).

The most abundant fish species in the marsh is the mummichog (*Fundulus heteroclitus*; Rodney 1990, Molines and Swarth 1996, Friebele 2001). Rodney (1990) estimated the population size of this species inhabiting the waters of one Jug Bay channel at 57,000. Mummichogs are well suited to the estuary due to the fact that they are very tolerant of changing environmental conditions. The adaptability of the Mummichog is due to its capacity to turn on and off 498 different genes associated with changing environmental conditions (Marshall 2010). They are able to tolerate a range of salinity from freshwater to saltwater, respond rapidly to changes in temperature, and survive in conditions of very high pollution (Waltz 2010). Mummichogs can survive when stranded in small shallow pools at low tide, tolerating very low dissolved oxygen and high temperatures. During extreme cold periods they burrow into the mud or move to deep channels (Bigelow and Schroeder 1953). Mummichogs feed on crustaceans, insects, and plant detritus. The majority of feeding takes place at high tide when the fish are able to feed at the marsh surface, leaving the marsh to return to deeper waters as the tide ebbs (Crumrine 1997). This species is an important prey species for both larger fish and birds (Molines and Swarth 1996). They are a critical link in the wetland food web, transferring energy from the marsh to the deep water areas (Crumrine 1997, Molines and Swarth 1996).

There are several ecological factors that can impact fish species including loss of submerged aquatic vegetation, chronic low levels of dissolved oxygen, commercial fishing, and high concentrations of suspended solids which can degrade spawning grounds. Water quality in the tidal freshwater system has a direct affect on the health of fish populations. Excess nutrients in estuarine waters can cause hypoxia or anoxia. Low dissolved oxygen creates stressful conditions for fish eggs and larvae, and can result in fish kills especially during the hot summer and times of drought. High temperatures increase the biological demand for oxygen. Swarth et al. (1996) studied the effects of low oxygen in relation to a prolonged heat wave during July of 1995 which resulted in a fish kill. After a week-long period of higher-than-normal temperatures, the researchers recorded anoxic conditions at two water quality monitoring stations for three successive low tides. Following this observation, hundreds of fish were found dead along the banks of the Patuxent (Nemazie & Swarth 1995). 237 dead fish were collected. Of those, *Morone americana* (white perch) made up over half (58%). *Perca flavescens* (yellow perch), *Menidia beryllina* (Atlantic silverside), *Fundulus diaphanous* (killifish), *Anchoa mitchilli* (bay anchovy), *Lepomis gibbosus* (pumpkin seed), and *Micropterus salmoides* (largemouth bass) were also collected. Dead fish ranged in size from 3.5 to 27.0 cm. These findings indicate that low oxygen is a very real threat to aquatic organisms.

The Patuxent River has a long history of bountiful fish populations. Even before commercial fishing became common, evidence points to a very productive fishing river. Native Americans left evidence of fishing in the river in the form of skeletal remains (Roylance 2010). John Smith was said to have fished on the Patuxent (Mansueti 1950), describing the Chesapeake watershed as "a delightsome land with clear rivers and brooks running to a faire bay." Once Europeans settled the area, commercial fisheries became a thriving industry, reaching their height in the late 19th century (Mansueti 1950).

Maryland DNR has records of commercial fish catches in the Chesapeake Bay since 1929. These records are used for stock assessment and to monitor fishery compliance with state regulations. Maryland DNR analyzed commercial fishing harvest records for the upper, lower, and entire Patuxent River from 1929–2004 to examine temporal trends of total fish catch, changes in main targeted species, species relative importance of total harvest, and comparisons between the upper and lower sections of the river (Dickey et al. 2008). This study serves as one source of information about fish population dynamics on the Patuxent River, although the methods of the data collection limit the interpretations that can be made. Commercial fishing data by itself cannot be used to estimate fish population trends, but it provides an estimate of human fish removal, a component of the overall population mortality. The data can be used to help understand dynamics in the fish populations at Jug Bay, which is situated in the upper portion of the Patuxent River and supports many commercially important fish species.

During the 75-year record, commercial catches in the Patuxent River showed two peak periods: the decade after World War II (1951-1956) and again in the mid-nineties (1997-2002) (Figure 3.4.23).

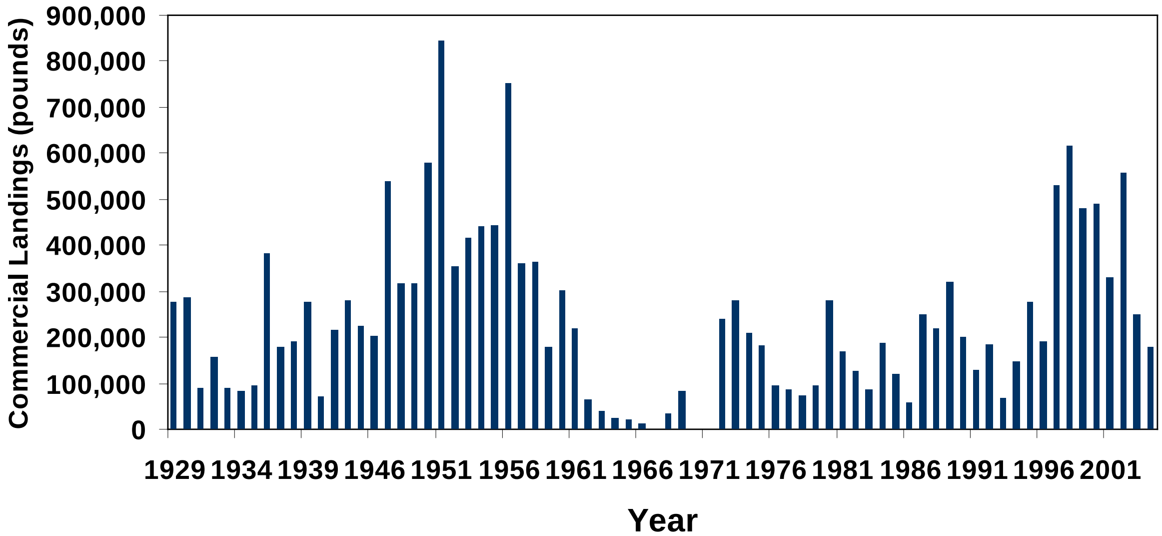


Figure 3.4.23 Total commercial harvest, based on landing records in the Patuxent River 1929–2004. Source: Dickey et al. 2008).

The main targeted species for the entire fishing record (1929–2004) were *Morone americana* (white perch), *Micropogonias undulates* (croaker), *Morone saxatilis* (striped bass), *Ictalarus* spp. (catfish), and *Dorosoma cepedianum* and *Brevoortia* spp. (herring). However, the main catches of the two peak periods differed substantially. Between 1951 and 1956, the main catches were croaker (47%), striped bass (20%) and white perch (12%). Between 1997 and 2002, the main catches were catfish (30%) white perch (25%) gizzard shad (21%) and striped bass (11%).

From 1972 until 2003, fishermen specified whether they harvested fish from the upper or the lower part of the Patuxent River. These two areas were separated by the Benedict Bridge. Total fish harvest between the upper and lower Patuxent did not vary dramatically between 1972 and 1990. However from 1990 through 2004, the upper Patuxent was much more heavily fished than the lower section of the river (Figure 3.4.24).

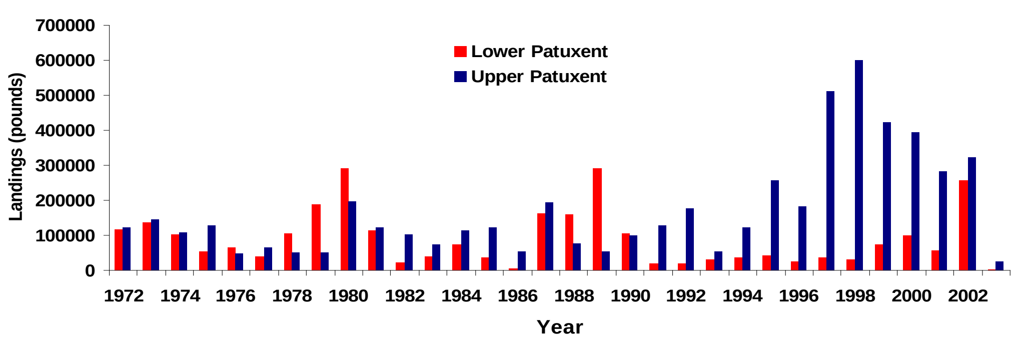


Figure 3.4.24 Total fish harvested in the Upper and Lower Patuxent River for the period 1972–2004. Source: Dickey et al. (2008).

From 1990–2004, catfish were the main targeted species in the Upper Patuxent, but not in the lower section. White perch and herring were important commercial species in both sections of the River, but contribute to the Lower Patuxent fishery in a greater percentage. The percentage of striped bass harvested was similar between the two sections of the Patuxent (Figure 3.4.25).

Lower Patuxent Species Composition 1990-2004 **Upper Patuxent Species Composition 1990-2004**

Figure 3.4.25 Patuxent river species composition for the Upper and Lower Patuxent River for the period 1990-2004. Source: Dickey et al. (2008).

Morone americana (white perch) is a locally abundant schooling fish found in estuaries. It prefers brackish water, but migrates upstream into fresh water to spawn. This species provided a major fishery throughout the entire 1929–2004 record. It showed three peaks of harvesting, in the early 1950s, 80s, and late 90s (Dickey et al. 2008).

Striped bass, also known as rockfish (*Morone saxatilis),* are Maryland's state fish and they provided a major fishery throughout the entire 1929–2004 record. Striped bass is an anadromous fish, spawning in the estuarine marshes and spending the majority of life in more saline waters. Jug Bay is the farthest upstream spawning area for this species in the Patuxent River. The marshes provide habitat for egg and larval development. As they mature, the striped bass return to the ocean. From 1985–1989 a striped bass moratorium was declared when it became endangered due to over-fishing and declining habitat, but after careful regulation it returned to the commercial fishing record as a strong component (Dickey et al. 2008).

Catfish, predominantly *Ictalurus punctatus* (channel catfish), has recently become a more important fish to the Patuxent commercial fishery, especially in the upper portion of the river. Herring (predominantly *Brevoortia tyrannus* and *Dorosoma cepedianum)* numbers have also grown considerably in the reported commercial harvest, particularly during the late 1980s. These species were always present in the records, but their increase in recent years reflects a growing market for *D. cepedianum* (gizzard shad) as fertilizer and *B. tyrannus* (menhaden) for fish oil, livestock feed and bait (Dickey et al. 2008).

3.4.6.2 Reptiles and amphibians

Reptiles and amphibians are very good indicator species for the health of wetlands due to their susceptibility to change in their environments (Friebele and Zambo 2004). The tidal and non-tidal wetlands and forested uplands of the Jug Bay Reserve provide very suitable habitat for more than 40 species of reptiles and amphibians (Smithberger and Swarth 1993). Both use the freshwater tidal marshes and forested uplands as their main habitat while the non-tidal wetlands serve primarily as nurseries for amphibians (Friebele et al. 2001). Some of the most common species found at Jug Bay include the red-bellied turtle, northern watersnake, eastern box turtle, marbled salamander and various species of frogs including the spring peeper, grey treefrog, green frog, bull frog and southern leopard frogs (Friebele et al. 2001). Complete species lists of reptiles and amphibians found in the Jug Bay area can be found at www.jugbay.org.

Reptiles and amphibians are a common focal point of numerous research studies conducted by staff and volunteers of the Jug Bay Wetlands Sanctuary. It is critical to understand the dynamics of these species considering their indication of ecosystem health. Sadly, the eastern box turtle as well as many other species of amphibians and reptiles are gradually disappearing from landscapes across North America mainly because of habitat loss and degradation. Turtles are specifically targeted for use as pets and are prey for raccoons or other animals (Swarth 2005b).

To bridge the gap and increase awareness on the importance of these species staff and volunteers have been involved with a variety of research efforts at the Sanctuary. The current and past reptile and amphibian research studies include the Marbled Salamander Migration Study, Vernal Pool Study, Frog Calling Survey, Red-bellied Turtle Nesting Study, Box Turtle Study, and The Great Herp Search. For more information regarding any of the studies discussed, contact the staff at the Jug Bay Wetlands Sanctuary or visit the website at www.jugbay.org.

Marbled salamander migration study

Ambystoma opacum (marbled salamander) and *Ambystoma maculatum* (spotted salamander) are common species in the Jug Bay area, but are rarely observed during random encounters. In 1988, Sanctuary staff and volunteers began a study to increase understanding and awareness of the breeding patterns of these salamanders. Every fall, salamanders leave their forested upland habitat and migrate to vernal pools to breed. The study examined relationships between migration and weather, the timing and duration of breeding activity as well as the migration patterns between male and females (Friebele et al. 2001; Molines and Swarth 1999). Since 1988, staff and volunteers have monitored amphibian breeding locations using drift fences and pit fall traps. Beginning in 1996, efforts were focused on three sites: Mark’s Pond, Forest Bluff, and Wet Forest. Sampling was conducted daily from September through November. Data collected included number of salamanders caught by trap, sex, and weight. Digital photographs were also taken for future identification of recaptures (Uimonen and Molines 2008; Friebele et al. 2001). Data was analyzed from the Wet Forest sampling location from 1994 through1996 by Molines and Swarth (1999) for the relationship between trapping of marbled salamanders and rainfall occurrence (Figure 3.4.26). Data indicated that 25% of marbled salamanders were trapped in conjunction with rainfall events, while 20% of captures occurred during no rain event. Furthermore, it should be noted that over half of the samplings resulted in zero captures during the absence of rain.

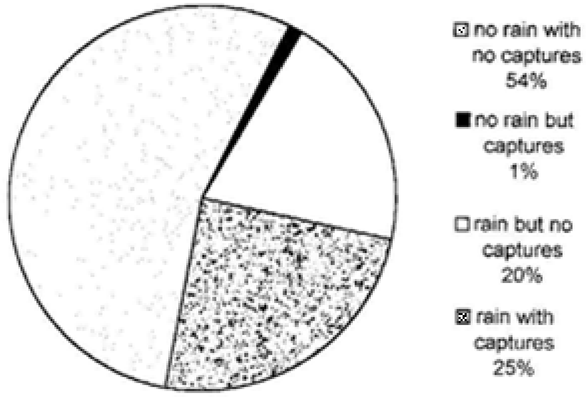


Figure 3.4.26 Percentage captures of marbled salamanders in relation to rainfall occurrence during the fall trapping season from 1994-1996. Data source: Molines and Swarth (1999).

Data analyzed by Molines and Swarth (1999) estimated the percent occurrence of spotted salamanders at four known trapping sites from 1995 through 1998 (Figure 3.4.27). The four known trapping sites were Temp Pond, Forest Bluff, Wet Forest, and Mark's Pond. Spotted salamanders not caught in traps were also included in the data estimation. Data indicated that spotted salamanders were dominantly located at Temp Pond (42%) followed by Forest Bluff (28%) and Wet Forest (19%) and interestingly, 9% of spotted salamanders were not captured in traps.

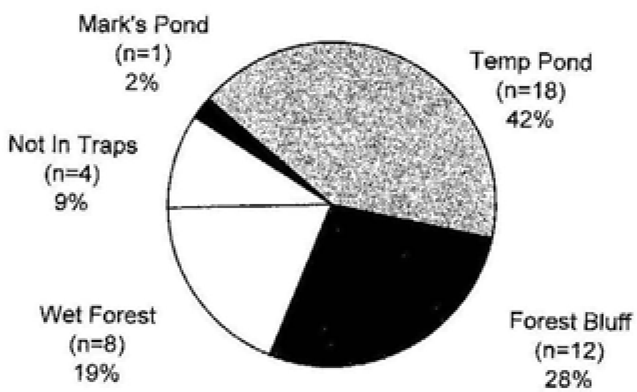


Figure 3.4.27 Number of spotted salamanders captured at five sampling sites during the spring and fall trapping seasons from 1995–1998. Data source: Molines and Swarth (1999).

Vernal pool studies

Vernal pools are temporary bodies of water that form when water from spring rainfall and winter snow collect in low forested depressions during spring. These pools are critical breeding habitat for reptiles and amphibians. The Vernal Pool Study monitors the activity of frogs, toads, and salamanders at various vernal pools located at the Sanctuary through bi-weekly samplings from early March through August. The objective of the study is to map the location of vernal pools, record the appearance of egg masses and larvae, track changes occurring with rainfall, and evaluate the diversity of frogs, toads, and salamanders utilizing the pools as breeding habitat (Friebele et al. 2001).

Frog calling survey

The vocalization of numerous different male frog species in the marshes and upland forested areas of Jug Bay comes to life during spring months. Frog calls are a mate attraction mechanism used to indicate the male's readiness to breed. Each species has its own unique call allowing Sanctuary staff and volunteers to listen and identify species and call location. Data parameters collected are frequency, intensity and duration of vocalizations. Surveys are conducted at sunset when frog calls are most frequent (Friebele et al. 2001).

Red – bellied turtle nesting study

Pseudemys rubriventris (red-bellied turtles) inhabit the deeper channels of the Patuxent River and the beaver pond in Two-run Creek. From late May to mid-July, females move from the river and wetlands to upland sandy areas to lay eggs (Swarth 2003). The red-bellied turtle nesting study began to better understand the nesting and egg laying habits of the females. Volunteers have endured hours-long observations required to watch the females dig their nests and deposit their eggs. Once the females had laid approximately 10-15 eggs, volunteers then capture and weigh the turtles, measure thier length, and uniquely mark the carapace. Then volunteers install an enclosure around the nest to deter predators. The goals of the program are to quantify red-bellied turtle using Jug Bay as nesting sites, hatchling averages, occurrence of females digging multiple nests, and environmental factors influencing hatching rates such as soil moisture and temperature. To date, the study shows that females return to the same sites year after year to lay eggs (Friebele et al. 2001). Between 1995 and 2000, 78 turtles were captured either by hand on the nesting grounds or in hoop traps set in aquatic habitats. In 2000, a marked female was observed laying two nests (one in June and the other in July) in the same season. This important discovery established that red-bellied turtles will lay multiple nests in the same season (Swarth 2003).

Box turtle study

Terrapene carolina carolina (eastern box turtles) inhabit the wetlands and forest of Jug Bay. During the hot summer months, box turtles are found buried in the mud to keep cool. To better understand habitat range and population dynamics, the Box Turtle Study was established in 1995. The study started by gathering volunteers to search for turtles in the forests and then give each a permanent mark by filing a small notch in the side of their shell (Swarth 2005b). Each turtle is uniquely marked on its carapace so that it can be properly identified at each sighting thereafter. The sighting of a previously marked turtle is noted and combined with other sightings to describe and map the home range of each individual. Data collected includes weight, length, and location. As of 2011, over 550 turtles have been found and marked within an 80-hectare (197 acre) study area (Swarth, personal communication). The cumulative number of individuals has quickly increased from 42 turtles in the beginning of the study to 530 turtles in 2007 (Figure 3.4.28).

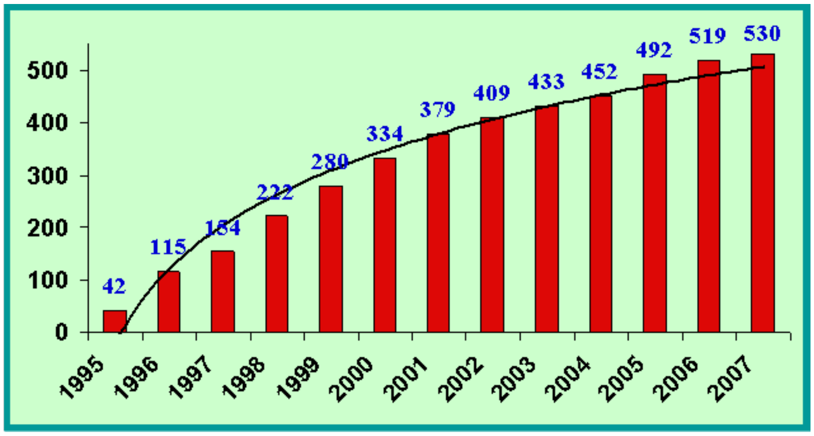


Figure 3.4.28 Cumulative number of box turtles marked each season at Jug Bay in a 50 ha study plot. Courtesy of Chris Swarth, Jug Bay Wetlands Sanctuary.

In 1998, the study was expanded to include radio telemetry. Through the use of radio telemetry the goals were shifted to assess the effect of habitat availability on movement patterns, home range sizes, and use of habitat (Marchand et al. 2003). Thread-trailing devices were placed on 14 eastern box turtles to monitor hourly and daily movements yielding a larger-scale of movement patterns. Three turtles were equipped with radio transmitters and monitored from July to October of 1998. The results of the study showed that box turtles use the uplands as well as the lowland wetlands further promoting that their habitat range is much larger than previously believed (Figure 3.4.29; Marchand et al. 2003). Eastern box turtle home ranges are often described as varying from less than one hectare to several hectares in size.

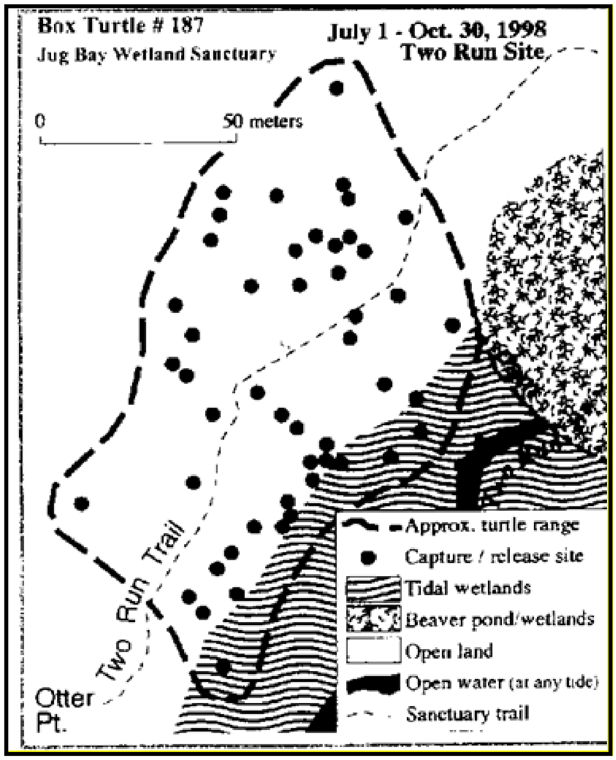


Figure 3.4.29 Home range of eastern box turtle #187 showing the use of both uplands and wetlands as habitat. Source: Marchand et al. 2003.

Beginning in 2000, radio telemetry was utilized to decipher home range characteristics of 41 different box turtles (25 females; 13 males; and 3 juveniles) of Jug Bay. Data analyzed from 2000 through 2004 illustrated that females have much larger home ranges and use more habitats compared to males (Figure 3.4.30). Understanding the differences in the use of the habitat between males and females is important for conservation efforts, especially for breeding-age females (Swarth 2005a).

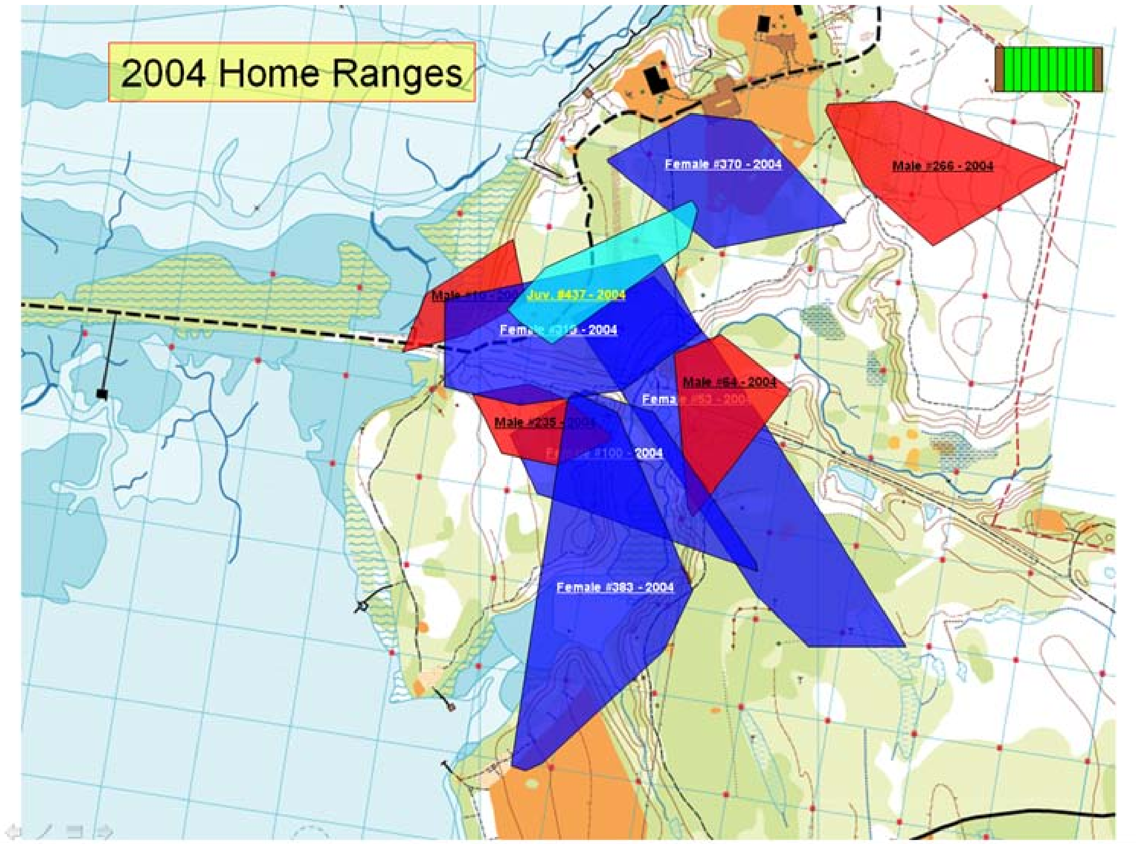


Figure 3.4.30 Home ranges of male and female eastern box turtles at Jug Bay from 2000 through 2004. Data Source: Swarth (2005a).

The great herp search

A study to determine the diversity of amphibians and reptiles in the Sanctuary was initated in 1989 and it is called “The Great Herp Search”. This is a one- and two-day annual survey that is lead by an expert and conducted with the help of volunteers who searched all habitats in the Sanctuary for these organisms. The search provides a way to accumulate information on habitat location and physical differences (coloration, length, and weight) of each species found in the Jug Bay area. It also allows volunteers to head outside and increase reptile and amphibian awareness with the goal of inspiring conservation and appreciation (Molines 1995). The data collected each year provides a mechanism to track herp population dynamics over a long period of time (Friebele et al. 2001).

In 2009, the Maryland Amphibian and Reptile Atlas (MARA) selected the Jug Bay Wetland Sanctuary as a test site for the characterization and mapping of the distribution of Maryland’s reptiles and amphibians. MARA is a collaborative effort between the Natural History Society of Maryland and the Maryland Department of Natural Resources. The atlas will be used mostly as baseline data to assess current state-wide distribution and to provide a baseline for understanding population changes that may take place in the future. The MARA state-wide effort began in

January of 2010 with the Sanctuary in full participation. For more information about this project, visit http://www.marylandnature.org/mara/.

3.4.7 Birds and Mammals

3.4.7.1 Birds

The wetlands and surrounding environs at Jug Bay provide critically-important habitat for resident and migratory birds. This is especially important in a region increasingly threatened with development. The Jug Bay area contains a variety of habitats and ecological communities that possess the food, cover, and nesting habitats that birds require.

Jug Bay has high species richness values and it is a refuge for more than 200 species of birds annually. The freshwater tidal system offers ecological features which are attractive to water birds, including open water and marsh, low salinity, and variable habitat resulting from daily tidal cycles. Mitsch and Gosselink (1993) described this type of system as potentially supporting the largest and most diverse wetland bird community in North America. Wild rice marshes and associated seed plants attract many migrating birds in the fall providing a rich source of carbohydrates allowing them to continue the migration journey. The open water provides fishing habitat for bald eagles, belted kingfishers, and osprey. Mudflats attract wading birds which forage for food during the tidal cycles. Twenty- two species of waterfowl use the water and marsh habitats during both the breeding and non-breeding seasons including tundra swans, Canada geese, wood ducks, green-winged teal and American black ducks. Floodplain areas, such as those associated with Two Run Creek support a variety of resident birds which nest in the trees, shrubs, and fern-covered banks. The meadow and shrub-land areas near the River Farm are managed for grassland birds which are in decline due to habitat loss.

Jug Bay Wetlands Sanctuary has been designated as an Important Bird Area (IBA) by the National Audubon Society. The IBA program is a global effort to identify and conserve areas vital to birds and biodiversity. Both of Maryland's Breeding Bird Atlas Projects (1983-1987 and 2002-2006) identified that the area around Jug Bay had 120 breeding bird species, the highest number for any location in the state. Over 200 bird species are observed at Jug Bay annually, and the overall species list stands at 300. The annual JBWS Christmas Bird Count now regularly documents over 110 species, making this the 2^{nd} or 3^{rd} best Christmas Bird Count location (in terms of species richness) in Maryland.

The Maryland Ornithological Society (MOS) lists several endangered species found at Jug Bay: *Thalasseus maximus* (royal tern), *Rynchops niger* (black skimmer), *Asio flammeus* (short-eared owl), *Contopus cooperi* (olive-sided flycatcher), *Cistothorus platensis* (sedge wren), *Lanius ludovicianus* (loggerhead shrike), and *Oporornis philadelphia* (mourning warbler). Maryland threatened species found at Jug Bay include *Haliaeetus leucocephalus* (bald eagle). Bald eagles are very common in winter (often 6-8 birds can be seen at once) and several pairs have nested in the Sanctuary and Patuxent River Park. Species at Jug Bay determined by the MOS to be in need of conservation include: *Botaurus lentiginosus* (American bittern), *Ixobrychus exilis* (least bittern), *Falco peregrines* (peregrine falcon), *Laterallus jamaicensis* (black rail), *Gallinula chloropus* (common moorhen), *Empidonax alnorum* (alder flycatcher), and *Oreothlypis* *ruficapilla* (Nashville warbler). The alphabetical list of birds (common names) found at Jug Bay is shown in Table 3.4.6.

Table 3.4.6 List of bird species (given by common names) found at Jug Bay. Species are listed in alphabetical order.

Acadian flycatcher
Alder flycatcher
American avocet
American bittern
American black duck
American coot
American crow
American golden plover
American goldfinch
American kestrel
American pipit
American redstart
American robin
American rree sparrow
American white pelican
American wigeon
American woodcock
Bald eagle
Baltimore oriole
Bank swallow
Barn owl
Barn swallow
Barred owl
Bay-breasted warbler
Belted kingfisher
Bicknell's thrush
Black rail
Black scoter
Black skimmer
Black tern
Black vulture
Black-and-white warbler
Black-bellied plover
Black-bellied whistling duck
Black-billed cuckoo
Blackburnian warbler
Black-capped chickadee
Black-crowned night heron
Black-neckedsStilt
Blackpoll warbler
Black-throated blue warbler
Black-throated green warbler
Blue grosbeak
Blue jay
Blue-gray gnatcatcher
Blue-headed vireo
Blue-winged teal
Bobolink
Bonaparte's gull
Broad-winged hawk
Brown creeper
Brown pelican
Brown thrasher
Brown-headed cowbird
Bufflehead
Canada goose
Canada warbler
Canvasback
Cape may warbler
Carolina chickadee
Carolina wren
Caspian tern
Cattle egret
Cedar waxwing
Cerulean warbler
Chestnut-sided warbler
Chimney swift
Chipping sparrow
Chuck-will's-widow
Cliff swallow
Common black-headed gull
Common grackle
Common loon
Common merganser
Common moorhen
Common nighthawk
Common redpoll
Common snipe
Common tern
Common yellowthroat
Connecticut warbler
Cooper's hawk
Dark-eyed junco
Double-crested cormorant
Downy woodpecker
Dunlin
Eastern bluebird
Eastern kingbird
Eastern meadowlark
Eastern phoebe
Eastern screech-owl
Eastern towhee
Eastern wood pewee
Eurasian wigeon
European starling
Evening grosbeak
Field sparrow
Fish crow
Forster's tern
Fox sparrow
Fulvous whistling-duck
Gadwall
Glaucous gull
Glossy ibis
Golden eagle
Golden-crowned kinglet
Golden-winged warbler
Grasshopper sparrow
Gray catbird
Gray kingbird
Gray-cheeked thrush
Great black-backed gull
Great blue heron
Great cormorant
Great egret
Great horned owl
Great-crested flycatcher
Greater scaup
Greater white-fronted goose
Green Heron
Green-winged teal
Hairy woodpecker
Hermit thrush
Herring gull
Hooded merganser
Hooded warbler
Horned grebe
Horned lark
House finch
House sparrow
House wren
Iceland gull
Indigo bunting
Kentucky warbler
Killdeer
King rail
Lapland longspur
Laughing gull
Least bittern
Least flycatcher
Least sandpiper
Least tern
Lesser black-backed gull
Lesser scaup
Lesser yellowlegs
Lincoln's sparrow
Little blue heron
Loggerhead shrike
Long-eared owl
Long-tailed duck
Louisiana waterthrush
Magnolia warbler
Mallard
Marsh wren
Merlin
Mississippi kite
Mourning dove
Mourning warbler
Mute swan
Nashville warbler
Northern bobwhite
Northern cardinal
Northern goshawk
Northern harrier
Northern mockingbird
Northern parula
Northern pintail
Northern saw-whet owl
Northern shoveler
Northern waterthrush
Olive-sided flycatcher
Orange-crowned warbler
Orchard oriole
Osprey
Ovenbird
Palm warbler
Pectoral sandpiper
Peregrine falcon
Philadelphia vireo
Pied-billed grebe
Pileated woodpecker
Pine siskin
Pine warbler
Prairie warbler
Prothonotary warbler
Purple finch
Purple gallinule
Purple martin
Red crossbill
Red knot
Red-bellied woodpecker
Red-breasted merganser
Red-breasted nuthatch
Red-eyed vireo
Redhead
Red-headed woodpecker
Red-necked grebe
Red-necked phalarope
Red-shouldered hawk
Red-tailed hawk
Red-throated loon
Red-winged blackbird
Ring-billed gull
Ring-necked duck
Rock dove
Rose-breasted grosbeak
Rough-legged hawk
Rough-winged swallow
Royal tern
Ruby-crowned kinglet
Ruby-throated hummingbird
Ruddy duck
Ruddy turnstone
Ruff
Rusty blackbird
Sanderling
Saltmarsh
Sharp-tailed sparrow
Sandhill crane
Savannah sparrow
Scarlet tanager
Scissor-tailed flycatcher
Sedge wren
Semipalmated plover
Semipalmated sandpiper
Sharp-shinned hawk
Short-billed dowitcher
Short-eared owl
Snow goose
Snowy egret
Solitary sandpiper
Song sparrow
Sora
Spotted sandpiper
Summer tanager
Surf scoter
Swainson's thrush
Swamp sparrow
Tennessee warbler
Thayer's gull
Tree swallow
Tricolored heron
Tufted titmouse
Tundra swan
Turkey vulture
Veery
Vesper sparrow
Virginia rail
Warbling vireo
Western sandpiper
Whip-poor-will
White ibis
White-breasted nuthatch
White-crowned sparrow
White-eyed vireo
White-rumped sandpiper
White-throated sparrow
White-winged scoter
Wild turkey
Willet
Willow flycatcher
Wilson's phalarope
Wilson's warbler
Winter wren
Wood duck
Wood stork
Wood thrush
Worm-eating warbler
Yellow Rail
Yellow warbler
Yellow-bellied flycatcher
Yellow-bellied sapsucker
Yellow-billed cuckoo
Yellow-breasted chat
Yellow-crowned night-heron
Yellow-headed blackbird
Yellow-rumped warbler
Yellow-throated vireo
Yellow-throated warbler

Bird surveys are an important component of monitoring. Surveys allow investigators to keep track of the species abundance and presence throughout the year and which species are local breeders. Several different surveys are done at JBWS: the MAPS program, the Patuxent Estuary Winter Waterbird Survey, the Jug Bay Winter Waterbird Count, and the Christmas Bird Count.

The Jug Bay Wetlands Sanctuary participates in the MAPS (Monitoring Avian Productivity and Survivorship) program, which is a continent-wide breeding season survey of songbirds started in 1989 by the Institute for Bird Populations in Point Reyes, California. About 1,000 stations operate nationwide each year (IBP 2011). The study aims to estimate annual survivorship through recapture of banded birds, determine annual post-fledgling productivity, and estimate adult population levels. Jug Bay initiated this monitoring program in 1990 and is the fifth oldest and longest-continuing station in the program (Teliak and Swarth 2008). Every summer during the breeding season 14 mist nets are set up to capture songbirds that are identified to species level. Birds are also aged and sexed for the record. Standard measurements of wing chord and weight for each bird are made, and a band is placed on the leg for identification. Sixty one species totaling over 2,400 birds have been banded since the inception of the study. Over the course of the study, JBWS has banded over 2,200 birds of 61 different species, 25% resident and 75% neo-tropical migrant species (Teliak 2005a, Teliak and Swarth 2008). Results of the study showed that seven species make up the majority of resident species: Carolina wren (28%), northern cardinal (29%), tufted titmouse (12%), downy woodpecker (6%), Carolina chickadee (5%), red-bellied woodpecker (2%), and blue jay (1%) (Swarth 1995). Five species comprise the majority of migrants: red-eyed vireo (21%), wood thrush (18%), Acadian flycatcher (17%), ovenbird (10%), and hooded warbler (5%) (Swarth 1995). The MAPS study also indicates that some migrant bird populations including those of Red-eyed Vireos and Wood Thrushes appear to be maintaining stable populations at Jug Bay, whereas in many other areas their populations are in steep decline (Teliak and Swarth 2008).

The Patuxent River Estuary Winter Water Bird Survey was conducted to document the diversity and distribution of water birds along the 72 km (45 mile) length of the Patuxent River estuary. The survey took place on a day in early February each year from 1999 to 2007, a time when migration is at a minimum and those species that are dependent on the estuary are present in large, stable numbers. Volunteers surveyed 100 points that were established along both sides of the river. A mean of 43,800 water birds of 52 different species were documented over the six years of the study, with the highest number (54,700) occurring in 2005 and the lowest number (32,100) occurring in 2000 (Swarth 2005c). The map of the estuary (Figure 3.4.31) shows how the river was divided into 9 km segments which were then used in the analyses to examine distribution. Jug Bay sits at the north end of the survey area, near the 72 kilometer mark.

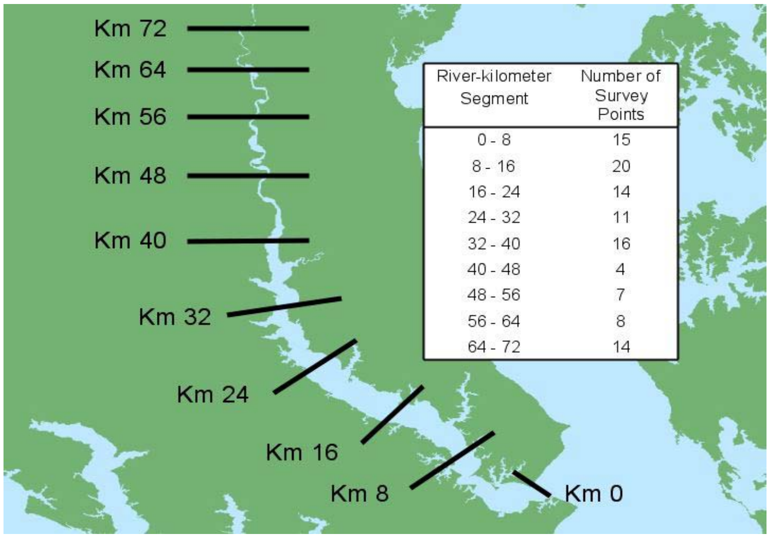


Figure 3.4.31 Patuxent River estuary showing the locations of bird survey points for the estuary winter water bird survey. Source: Swarth 2005c.

Figure 3.4.32 shows the distribution of all water bird species combined (about 40 species) along the length of the estuary. The mid-point of the estuary, from 16 to 40 kilometers (10 to 25 miles) up from the mouth at Solomons, consistently supports the greatest numbers (Swarth and Burke 1999, Swarth 2001). The most abundant species were *Cygnus columbianus* (tundra swan), *Branta Canadensis* (Canada goose), *Aythya valisineria* (canvasback), *Aythya marila* (greater scaup), *Aythya affinis* (lesser scaup), *Bucephala clangula* (common goldeneye), *Bucephala albeola* (bufflehead), *Clangula hyemalis* (long-tailed duck), *Oxyura jamaicensis* (ruddy ducks), and *Larus delawarensis* (ring-billed gull). At river segment 72, the location of Jug Bay, the number of water birds is quite high (Figure 3.4.32).

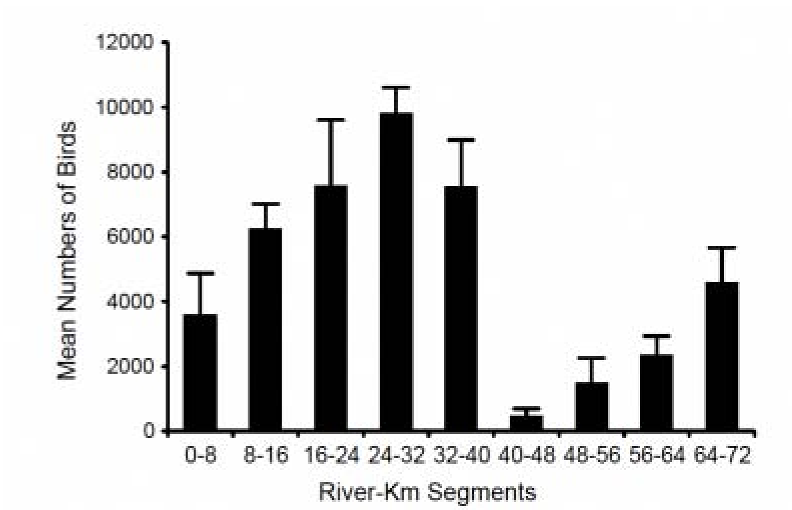


Figure 3.4.32 Mean number of waterbirds occurring at each of the 8 km river segments along the Patuxent River estuary. Patuxent river estuary winter water bird survey, Jug Bay Wetlands Sanctuary: http://www.jugbay.org/. Source: Swarth (2005c).

Researchers found that the distribution of waterbird species was highly habitat specific (Swarth 2005c). Long-tailed ducks were common only in the lower estuary, whereas Ruddy Ducks and Canvasbacks were more common between river segments 32 and 40. Dabbling ducks were most common in the freshwater tidal region (river-km 64-72). Information from the Winter Waterbird Survey was used to study the relationship between the locations of birds and their prey along the length of the Patuxent River from the Chesapeake Bay to 72 river km (45 miles) upstream at Hill's Bridge. The study showed that prey species are a driving force in duck habitat preference: diving ducks occupy species-specific ranges along the river where their preferred benthic food source is concentrated (Swarth and Ricciardi 2008).

The Jug Bay Winter Waterbird Count was created to identify the species of birds that spend the winter on the river and in the marshes. Migratory water birds like terns, egrets and rails leave the area while many others move in including species of ducks, swans, geese, wading birds and raptors. The survey was conducted every other week from October to April beginning in 1990. Information collected was used to monitor seasonal and year-to-year trends in water bird presence. After a decade of study, two main trends were found: first, that total numbers of birds are highest in mid-winter, and second, that total numbers of species are highest in fall and early spring (Swarth 2000, Swarth and Burke 2000). Population numbers are lowest in fall and early spring and highest in winter months. This is because gulls and waterfowl with flocks numbering in the thousands (primarily Ring-billed Gulls, Herring Gulls, Canada Geese, American Black Ducks, Mallards and Green-winged Teal) overwinter in the Jug Bay area. As spring approaches, birds move north and west toward breeding grounds. The number of species is highest in fall and spring and lowest in mid-winter because of the many migrant species associated with those migration periods. Long-term studies such as this are crucial for tracking changes in the local environment and documenting population fluctuations (Swarth 2000, Swarth and Burke 2000), as well as for discerning changes such as habitat loss that may be taking place at breeding and over-wintering locations. The observations made during the study were consistent with broader geographical trends (Swarth 2000, Swarth and Burke 2000).

The Eastern Bird Banding Association's fall songbird migration study takes place at 10 locations from mid-August through mid-November each year. One of the locations for the study is the Jug Bay Bird Observatory at River Farm at Jug Bay. The Jug Bay area is recognized as a very important habitat to migratory songbird species (Teliak 2005b). Data from the study are used both locally and regionally to monitor the numbers, species, and conditions of migrating songbirds along the eastern U.S. flyway. At River Farm, twenty-six mist nets are set before dawn throughout diverse habitat for 42 days during the study period. The local study data points to trends in songbird migration such as expected arrival and departure times, and expected numbers of migrants of each species. Data combined over the 13 years of the study provides a powerful tool for comparing a current year's data. Notably, both species diversity and number of birds captured declined throughout the period from 2001–2004 (Goodwin 2004, Teliak 2005b). Population declines are chiefly caused by habitat loss in the breeding/wintering range or along stopover points of the migration routes. Unfavorable weather can also affect survival rates.

Efforts to improve habitat for birds in the Jug Bay area are ongoing. Creation of meadow and shrub habitat, restoration of the wild rice marshes, and extirpation of invasive species help to support the organisms which use these habitats.

Several bird monitoring groups reported that bird species associated with grassland and shrub-land are in serious decline due to the conversion of farmland and grassland into houses, roads, and commercial development (Bystrak 1998). Funding was received by JBWS from the USDA and the Friends of Jug Bay in 1997 to convert former farmland into into a warm season grass meadow and shrub-land habitat suitable to attract species threatened with decline including eastern meadowlark, yellow-breasted chat, American woodcock, eastern towhee, prairie warbler, bobolink, grasshopper sparrow, and savannah sparrow. This habitat is currently used by many species of resident and migrant birds; however, none of the targeted species appear to make extensive use of the meadow.

In the early and middle parts of the 20th century, sora and bobolinks arrived to the marsh in large numbers to take advantage of the plentiful seeds of marsh plants during the fall migration (Meanley 1975). *Zizania aquatica* (wild rice), millet, and *Polygonum* spp. (smartweeds) which ripen in the fall provide food and cover for resident birds as well as migrating birds. Within the past four decades, decreases in the productivity of some marsh plants, especially wild rice, concided with a decline in local populations of certain migratory marsh birds including soras and bobolinks. Jug Bay was one of the most popular sora (*Porzana carolina*) hunting locations in the region because of the abundance of the grain plants (Mitchell 1933). Even into the 1980s, dozens of sora were present in the marsh, fattening up for their fall migration trip. With the decline of wild rice in the 1990s, the sora became absent (Friebele 2001). At present, sora are listed as uncommon or extremely rare at Jug Bay. Once, 10,000 boblinks could be seen on the Patuxent on their fall migration trip (Meanley 1975), but are currently rare to absent from the wetlands (Friebele 2001). Efforts to restore wild rice and associated grain species since the 1980's have increased the number of birds returning to Jug Bay marshes on their fall migration trips. Park managers hope that continued restoration and preservation activities will bring even greater numbers of Soras and Bobolinks back to the marsh (Friebele 2001).

Due to the decline in the sora population, there is great concern for their success. To study survivability during fall migration, Haramis and Kearns (2000) attached radio transmitters to 110 soras. They found that at least 69% and as much as 92% of the sample successfully migrated from Jug Bay. Kearns et al. (1998) found that by using recorded calls of sora and Virginia rail (*Rallus limicola*) and by improving trap design, they were able to achieve higher numbers of capture for the purpose of banding. The outcome of this study was that banding records of sora for North America were doubled. It demonstrated the importance of banding these birds in fall and winter migration stopovers to better understand the migration process.

Pandion haliaeutus (osprey), a migrant tidewater species return from South America to Jug Bay every year in early March. Longterm monitoring and banding of this species at Jug Bay has shown that the arrival time of these birds to the Jug Bay area has moved earlier by about two and half weeks, from the regular March 18th to March 1st (Greg Kearns 2011, personal communication), which may be associated to climate change. The ospreys nest primarily on artificial platforms erected in the river (by staff from the Patuxent River Park at Jug Bay), although during the last years they have started to nest in other structures including cel towers (Greg Kearns 2011, personal communication). Ospreys fish similarly to eagles by soaring over the water and plunging to catch a fish. In the 1960s and 70s osprey population numbers had dropped significantly due to thinning eggshells caused by the pesticide DDT in the aquatic environment. Since the banning of DDT, populations of birds living on or near water, including ospreys, have recovered. During the early 2000's the Chesapeake Bay area hosted about 20% of all nesting ospreys in the contiguous United States (Swarth 2002). Jug Bay has a particularly high population of nesting pairs (12 pairs were reported during the 2002 breeding season and about 35 during the most recent 2011 breeding season) and numbers on the Patuxent River are among the highest on the east coast (Swarth 2002). As part of the longterm banding project conducted at Patuxent River Park, a total of 50 new ospreys were banded in 2011 within Jug Bay and a total of 300 were banded during 2010-11 along the lower 45 miles of the Patuxent River. In an effort to learn more about feeding habits, behaviour, etc. of ospreys, two web cams have been established in two nest sites, and live records of these birds could be observed at: http://www.pgparks.com/page332.aspx (Greg Kearns 2011, personal communication).

Resident Canada geese have become an invasive species at Jug Bay over the last three decades and were largely responsible for declines in the wild rice population. Canada geese out-compete other species by inhabiting areas removed from hunting, breeding early in life, laying large clutches of eggs, nesting in sites more hospitable than those chosen by other species, and by avoiding the hazards of migration (Friebele 2001). This species will be addressed further in the section on invasive species (3.5.2.3).

Reports of losses and declining quality of emergent wetland habitat in North America in the last century are abundant (Tiner 1984, Wilen and Frayer 2004). With these reports comes more information about declines in bird species that occupy these habitats (Bellrose and Trudeau 1988, Pulliam and Danielson 1991). The U.S. Fish and Wildlife Service has recognized that bird species occupying wetland habitats are of special concern and their status and population trends need to be studied and followed (U.S. Fish and Wildlife Service 2002). Jug Bay Wetlands Sanctuary readily participates in the monitoring of wetland bird species using the protocol designed by Conway (2007). Monitoring marsh birds and evaluating population trends allow resource managers to evaluate the status of each species to determine if threats to bird populations are present. The abundance, presence, or absence of bird species can also provide information about wetland health and integrity. Swarth (2003) developed a biological assessment method to determine the health of wetlands using bird species as indicators. He used existing knowledge of bird species and their sensitivity to vegetation, water factors, water quality, and human disturbance to create an Index of Biological Integrity (IBI) for wetlands. Swarth's IBI is used to rate the relative condition of a wetland and determine strategies for management and restoration.

3.4.7.2 Mammals

The marshes and upland habitat of Jug Bay provide homes for various native and invasive species of mammals. Some of the most common native species are *Procyon lotor* (raccoon), *Castor canadensis* (beaver), *Vulpes vulpes* (red fox), *Mephitis mephitis* (striped skunk), and *Odocoileus virginianus* (white-tailed deer). Species present at Jug Bay, but rarely observed include *Neovison vison* (mink), *Glaucomys volans* (southern flying squirrel), and *Zapus hudsonius* (meadow jumping mouse) (Swarth 2008). There is is poor data on mammals present in the Jug Bay area, especially for bats and small mammals such as shrews, rodents, etc.

White-tailed deer populations have been increasing in the Jug Bay area as well as numerous other locations in Maryland since the 1980s. A survey to estimate the population of white-tailed deer around the Sanctuary was initiated in June of 2005 to yield a greater understanding of habitat alterations as a result of increased populations (Campo 2006). It is apparent that increased herbivory associated with more deer is creating a loss of habitat at the Jug Bay component of the Reserve.

Other than the white-tailed deer population characterization, there is little mammal monitoring occurring at the Jug Bay Wetlands Sanctuary and Patuxent River Park. The only quantification of mammals is during the yearly BioBlitz held at each location. The 2007 BioBlitz at the Sanctuary identified seven mammal species, including the beaver, eastern chipmunk, eastern cottontail, gray squirrel, muskrat, red fox and white-tailed deer. A complete list of mammals found at the Jug Bay Wetlands Sanctuary can be found at http://www.jugbay.org/research/species_lists. Results from the 2007 BioBlitz are available at www.jugbay.org. Furthermore, the first BioBlitz of the Patuxent River Park was held in 2009 and a total of 11 species of mammals were identified, including red fox, beaver, white-tailed deer, Virginia opossum, eastern cottontail, muskrat, white footed mouse, raccoon, groundhog, eastern gray squirrel and eastern chipmunk. Results from the 2009 BioBlitz can be found by contacting the staff at Patuxent River Park.

3.5 DISTURBANCES AND STRESSORS

The Patuxent watershed is affected by natural and anthropogenic factors including flooding, storm damage, periodic events at different temporal and spatial scales (tidal regimes and pollution, including sediment, nitrogen and phosphorus) as well as other human-induced disturbance.

3.5.1 Natural Disturbances

The largest natural disturbances that have shaped Jug Bay include glaciation and inter-glaciation periods. During these periods, sea level rose and fell eroding and depositing sediments on the shorelines. However, much of the distribution of sediments and native and non-native vegetation has been instigated by human activities throughout history, in turn impacting the natural processes of the environment (Grumet 2000).

Wet-dry periods, storm events, and hurricanes are also important natural disturbances. Over the past 2,000 years, in the mid-Atlantic region, alternating dry and wet periods have been documented. Extended dry periods were recorded during the seventh century, between 1000 and 1250, in 1400, and between 1580 and 1610 (Willard et al. 2003). The sixteenth and early seventeenth century droughts exceeded twentieth century droughts in their severity as recorded by North American tree-ring records and early colonists. In contrast, wet periods dominated during the tenth and fourteenth centuries and between 1610 and 1750 (Cronin et al. 2000; Willard et al. 2003). During the past 500 years, wet periods occurred approximately every 60 to 70 years and lasted less than 20 years (Cronin et al. 2000). A detailed list of weather and storm events for counties surrounding the Jug Bay area including blizzards, droughts, flooding, hail, rain, snow, thunderstorms, tornadoes, winter weather and windy conditions are available at www.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent/storms. The major hurricanes and tropical storms recorded in the Jug Bay area include the Hurricane of 1933, Hazel (1954), Agnes (1972), and Isabel (2003) (Frieble et al., 2001). Associated impacts of these hurricanes include shoreline erosion which caused significant sedimentation and coastal flooding (Frieble et al. 2001; Hennesse and Halka 2004).

Biological activities also create natural disturbances in the environment. As described in the summer 2010 version of Jug Bay Wetlands Sanctuary's Marsh Notes, *Castor Canadensis* (beavers) have been known to occupy Jug Bay's Two Run Branch and Galloway Creek. Beavers build dams to create waters deep enough to provide a safe habitat to escape predators. However, some beavers at Jug Bay live in lodges in the marsh without dams. In the late 1980s, beavers built a dam near Otter Point creating the pond at Two Run Branch. Soon after, another dam was built upstream from the first, creating two ponds. Initially, the permanent water killed large trees allowing a variety of terrestrial fauna to utilize the fallen trees. By 2000, conditions were favorable for both aquatic flora and fauna. In conjunction with the dams built by beavers, lodges are also frequently constructed and then abandoned in this area. Numerous studies have documented the benefits of beaver ponds; those benefits include increased water quality through microbial actions on nutrients, increased rates of sediment deposition, and the creation of diverse habitat within tidal freshwater marshes.

Figure 3.5.1 Wild rice (*Zizania aquatica*) and resident Canada geese (*Branta canadensis maxima*).

Wild rice (*Zizania aquatica*) has experienced a major decline in the 1990s at Jug Bay, which is mainly attributed to the increasing populations of non-native resident Canada geese (*Branta canadensis maximia*) in the area (Figure 3.5.1) (Haramis and Kearns 2007). A population of resident Canada geese was established in the Jug Bay area beginning in the 1970s. By the mid-1990s, as the population steadily grew, signs of their effect on the wild rice became apparent. In 1999, restoration efforts were initiated to protect the wild rice, including the installation of protective barriers, introduced wild rice plantings, application of herbicides to areas colonized by phragmites, and implementation of a summer hunting season of Canada geese. Changes in wild rice densities were tracked and quantified using aerial photographs and Geographic Information

System (GIS) mapping for five different years: 1989, 1999, 2003, 2005, and 2007. The results show a shift from high acreage of wild rice to lower densities followed by increased densities (Figure 3.5.2). From 1989 to 1999, approximately 275 acres of wild rice were lost. From 2000 to 2007, restoration efforts have successfully restored 196 acres (Delgado et al. 2009, unpublished data).

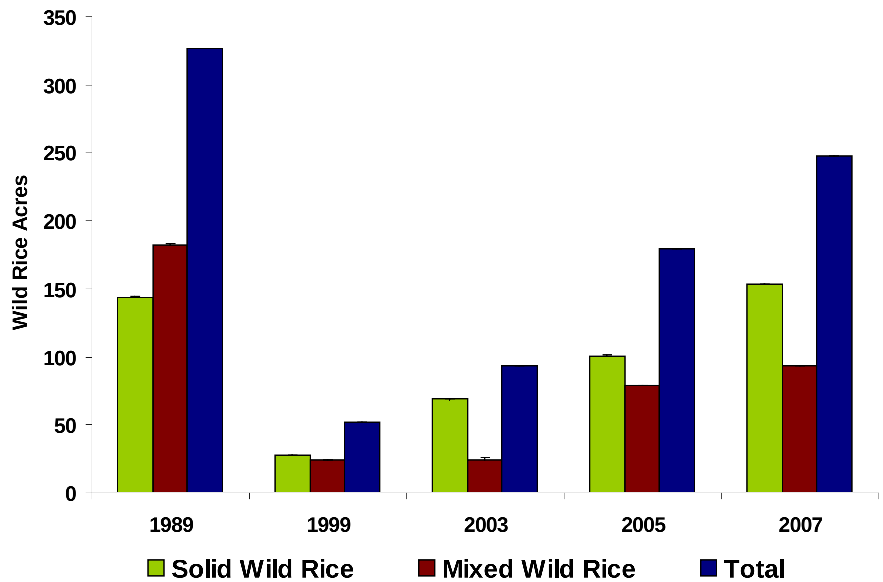


Figure 3.5.2 Wild rice density shifts (in acres) from 1989 through 2007 as a result of resident Canada geese herbivory and resulting restoration efforts. Source: Delgado et al. (2009, unpublished data).

Mute swans (*Cygnus olor*) are resident, non native birds present in the Chesapeake Bay area. They exclusively graze in shallow wetlands and can negatively impact underwater grass communities through direct consumption, interruption of SAV reproduction, and by trampling and uprooting SAV (Maryland DNR Wildlife and Heritage Service 2003). According to the 2007 Jug Bay Wetlands Sanctuary Bioblitz, mute swans are present at Jug Bay in small numbers and they are not typically seen in the upper Patuxent River. In the lower Patuxent River, where populations are larger and more common, mute swans can have significant impacts on submerged aquatic vegetation (SAV).

3.5.2 Anthropogenic Stressors

The Jug Bay Reserve is among several systems that are extremely vulnerable to anthropogenic stressors that are a result of increased human populations. One primary stressor of great concern that is linked to human activity is development. Development results in run-off containing nutrients, contaminants, sediment, and consequential decreased dissolved oxygen conditions. Other stressors discussed in great detail are the impacts of invasive species and climate change.

3.5.2.1. Development

Historically, the area between the Potomac and Patuxent Rivers was inhabited by tribes of Native Americans and it was known as the "Piscataway Nation." Development of the lands of the Patuxent River did not begin until John Smith and the English settlers arrived. Tobacco was a very important cash-crop of the English settlers and therefore yielded the first cultivation of land along the Patuxent River. This began the human stress on the Patuxent River and Jug Bay and would determine all future development. As tobacco became a more important crop and Jug Bay became an important export and shipping location, more and more acres of forest were stripped to create farmland for tobacco. Development of the watershed continued and by 1692, settlers were beginning to realize that farming resulted in increased river siltation and further began to understand the harmful consequences (Frieble et al. 2001).

After the War of 1812, the invention of the steamboat further increased the value of the tobacco crop resulting in greater clearing of forested habitat for farming. Sedimentation along the Patuxent River exacerbated to the point that the Army Corps of Engineers had to dredge a ten-foot deep channel, 450 feet long in 1888 and again in 1905 to allow the steamboats to reach locations of tobacco export. By 1896, the Chesapeake Beach Railroad was completed yielding transportation from Washington D.C. to Chesapeake Beach (Frieble et al. 2001).

After World War II, the Patuxent's watershed became increasingly developed. As Tom Horton stated in *Bay Country*, "New urban and suburban development would soon consume a greater percentage of land in the Patuxent basin than any other river system of the Chesapeake's sprawling drainage, from New York State to West Virginia" (Horton 1987). The population living in the Patuxent River watershed in 1950 was estimated at approximately 86,000 people. By 2000, there were approximately 500,000 people inhabiting the Patuxent River watershed, the main attracting cities being Baltimore and Washington D.C. With the increase in population came the introduction of wastewater treatment plants. Wastewater treatment plants along the Patuxent yielded three million gallons of wastewater discharger per day in 1963 and by 1989 were creating as much as 40 million gallons of discharge per day. The wastewater effluent combined with agricultural run-off loaded the river with nutrients (Frieble et al. 2001).

In 1950 the annual load of sediment entering the Patuxent was 160,000 tons; by 1980 it was estimated at 710,000 tons (Frieble et al. 2001). As it rained, sediment and nutrients would runoff the land decreasing water clarity and creating nutrient enriched waters. Decreased water clarity and excess nutrients block out essential sunlight necessary for the growth of submerged aquatic vegetation (SAV). SAV provides habitat and food sources for fish and waterfowl; therefore, the decline of native SAV negatively impact animal species strongly dependent upon them.

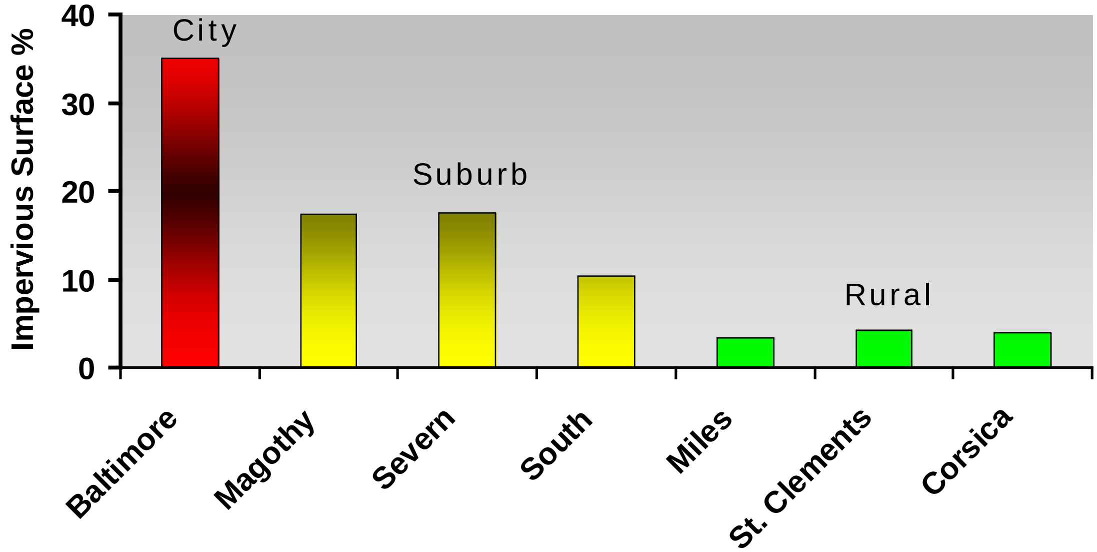


Figure 3.5.3 Relationship between impervious surface and development for various watersheds within the Chesapeake Bay. Source: Uphoff et al. (2008; unpublished data).

A major component of development is increased impervious surface cover, including the construction of roads, parking lots, roofs, and other human structures. Overall, urbanized areas have larger impervious surface coverage than more rural areas (Figure 3.5.3). One of the main concerns regarding impervious surface is the blockage of natural seepage of rain into the ground, which often translates into alterations in flow regimes. Subsequently, this runoff is commonly associated with increased nutrients, contaminants, erosion, sediment transport, and decreased dissolved oxygen conditions downstream into the estuaries. Data regarding impervious surface percentages were quantified for all of Maryland (Figure 3.5.4). The Patuxent River falls with predominantly within the 5-12% category with locations also falling in the 12-42% category.

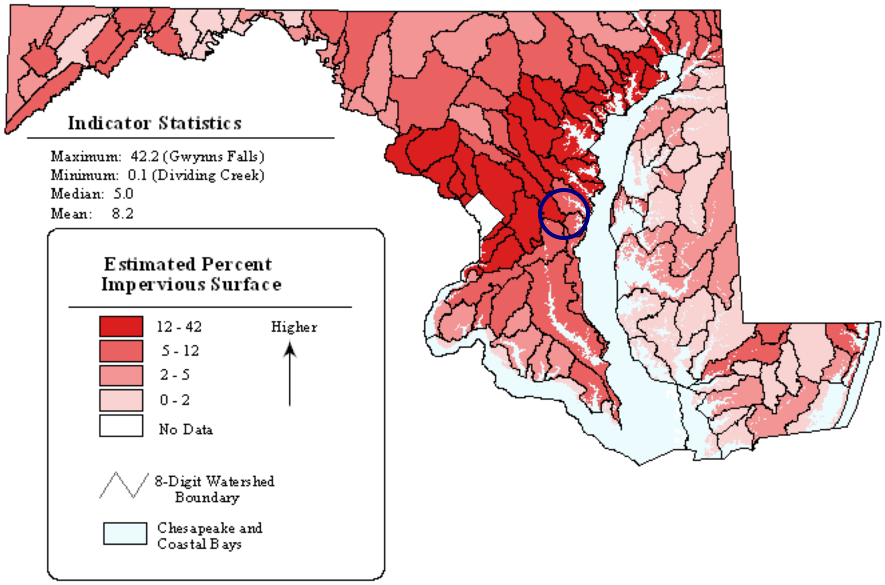


Figure 3.5.4 Percent impervious surface within the Chesapeake Bay. The Patuxent River watershed (within blue circle) falls within both the 5-12% and 12-42% categories. Source: Maryland's surf your watershed (http://www.dnr.state.md.us/watersheds/surf/index.html).

In the midst of increased impervious surface and development, the Jug Bay Wetlands Sanctuary was established to protect lands adjacent to the Patuxent River. A protest by political leaders and local neighbors in 1970 allowed Anne Arundel County to gain control and deem Sanctuary lands. Since then, five neighboring parcels have been purchased to expand the Sanctuary's footprint to about 1,400 acres (Faber 2007). In 1990, Jug Bay was named a National Estuarine Research Reserve becoming one of three Reserves in the Chesapeake Bay, Maryland Reserve system.

3.5.2.2. Climate Change

Climate change is a major topic of concern and focus within national and local government agencies, non-government affiliates, and within sections of the general public. In April 2007, Governor Martin O'Malley established a Maryland Commission on Climate Change (MCCC). In August of 2009, the MCCC published a Climate Change Action Plan which characterizes the projected impacts and effects of climate change on the Chesapeake Bay, its people, and its coastal ecosystems. The Chesapeake Bay is one of the most vulnerable estuaries in the country regarding the impacts of climate change, a result of accelerated sea level rise and land subsidence during the 20th century (Boesch et al. 2008). The Jug Bay Reserve is located within the upper Patuxent River, which is a tributary along the western shore of the Chesapeake Bay. This location makes it vulnerable to potential climate change impacts, which include sea level rise, salinity intrusion, and altered temperature and precipitations regimes. Climate change impacts have the potential to push the tidal marsh wetlands further inland. Baldwin et al. (2001) determined that plant species composition in tidal freshwater marshes is to some extent controlled by year-to-year changes in hydrology, and that long term changes caused by sea level rise will reduce species diversity. Site managers at both Patuxent River Park and Jug Bay

Sanctuary have noticed an increase in the high tide line over the last decade of about 3 inches (Greg Kearns, personal communication). Change in sea level could be due to sea level rise or geologic subsidence, or a combination of both. An important area of study is the impending rise in sea level and how this will affect the emergent marsh communities in this area.

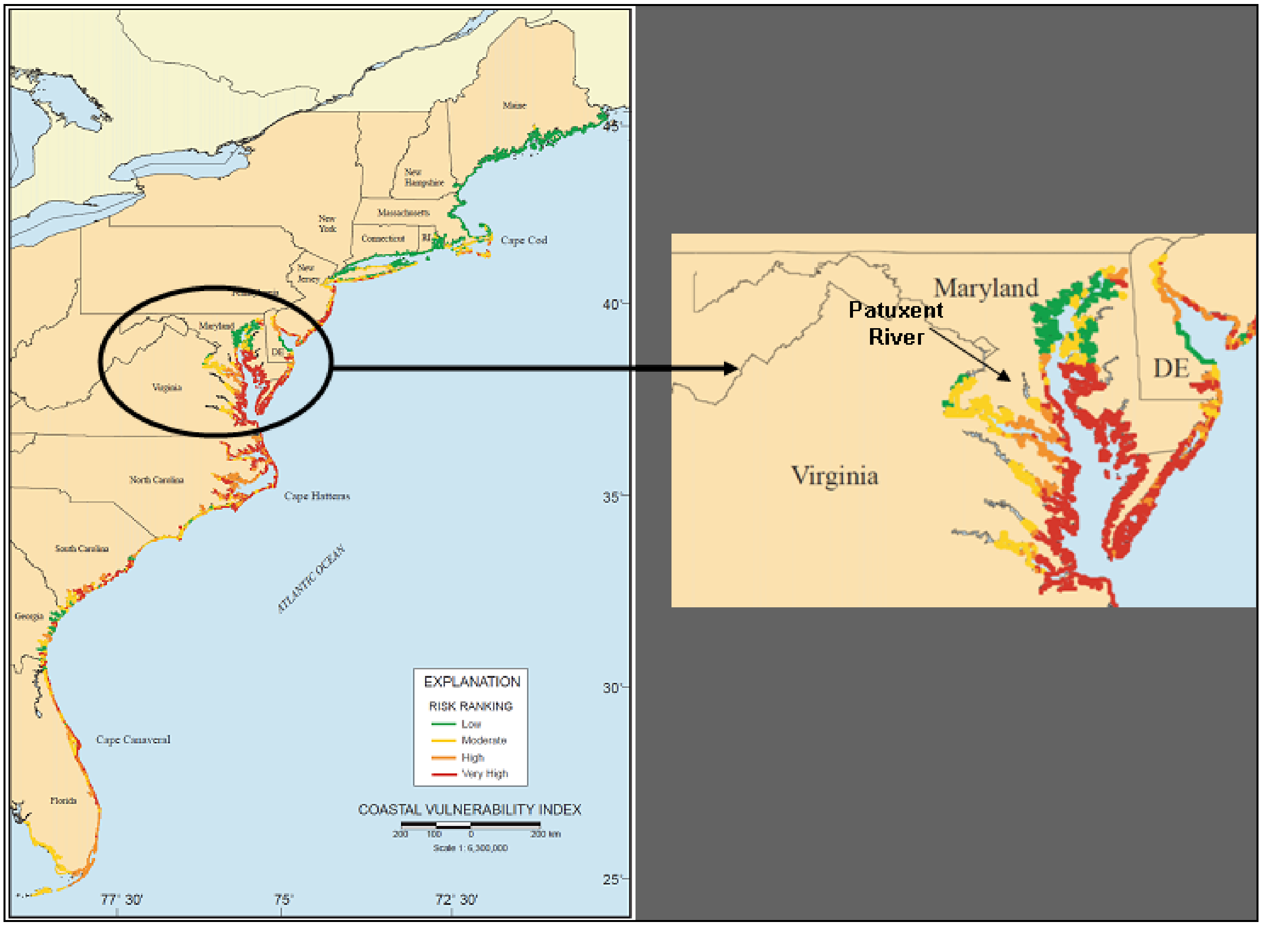


Figure 3.5.5 Coastal Vulnerability Index of the East Coast further highlighting the risk of the Chesapeake Bay and its tributaries (including the Patuxent River). Source: Robert Thieler, USGS (2000).

The U. S. Geological Survey (2000) created a Coastal Vulnerability Index indicating the level of risk for the east coast (Figure 3.5.5). The index ranks coastlines from low, moderate, high, to very high risk. The Chesapeake Bay shorelines rank from very high risk along the eastern shore to moderate/low risk along the upper shores. The Patuxent River ranks high risk along the mouth of the river to moderate risk along the upper sections. In addition, the NOAA station at Solomons Island, which is located at the mouth of the Patuxent River, estimated a rise in sea level of 3.41 mm (0.13 inches) /yr from 1937 through 2006 (Figure 3.5.6). This equates to a change of approximately a 34 cm (1.12 ft) rise in 100 years.

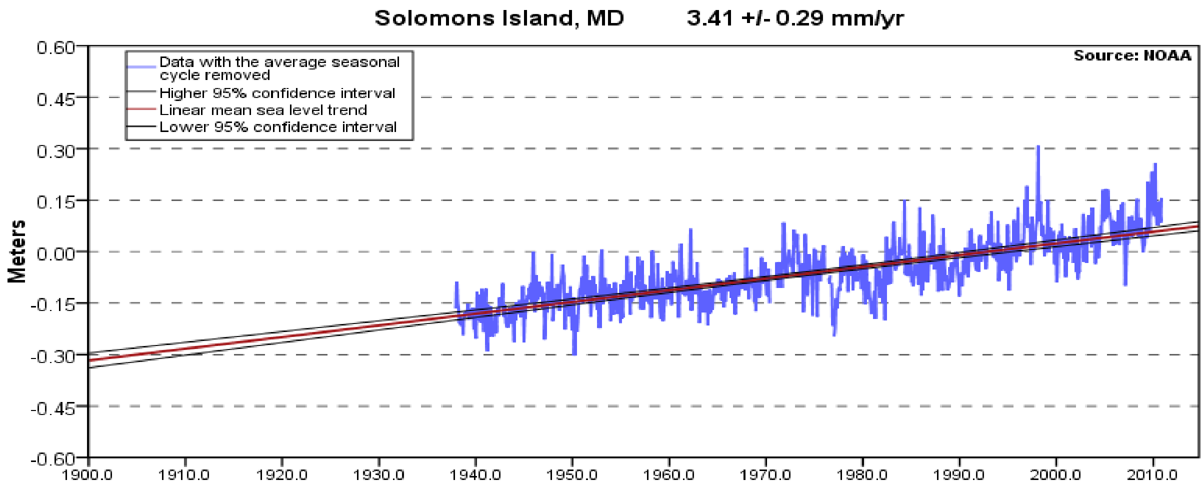


Figure 3.5.6 Average sea level rise in Solomons Island, Maryland from 1900-present. Source: CO-OPS - Center for Operational Oceanographic Products and Services (2008).

Tidal freshwater marshes can keep pace with sea level rise if sediment accretion yields elevations that are relative to the tidal range. If the marshes do not keep pace, increased flooding will cause water logging and changes within marsh soil chemistry. If vegetation becomes too stressed, species composition will shift to favor more flood tolerant plants. There is also the possibility of conversion to open water mud flats (Shellenbarger 2008). A wetland's ability to migrate depends on the availability of space and the appropriate slope of the upland transitional area. The majority of marsh plants found at Jug Bay are not completely flood tolerant species; most only tolerate intermittent tidal flooding (Table 3.5.1). The most abundant plants in the low to mid marshes of Jug Bay are *Nuphar advena* (spatterdock), *Zizania aquatica* (wild rice), and *Pontederia cordata* (pickerelweed) and *Peltandra virginica* (arrow arum). If sea level rise follows the CO-OPS projections, these low marsh plants will become flooded. If accretion does not keet pace with sealevel rise these plants will be forced to migrate landward assuming space is available and the slope of the land is appropriate. (Figure 2.5.6, Climate Change section, Otter Point Creek).

Table 3.5.1 Salinity and flooding tolerances of the dominant species of the low, middle and high marsh habitats located at the Jug Bay Reserve.

Salinity Range: ≤ 0.2 ppt | ≤ 0.4 ppt | ≤ 7.5 ppt | ≤ 10 ppt | Flood-tolerant plants

Species	A/P*	Salinity Tolerance[1]	Flooding Tolerance
Low Marsh			
Nuphar advena	P		
Zizania aquatica	A	0.37 ppt[2]	Reduced size & seed production with 30 – 50 cm flooding[5]
Pontederia cordata	P		
Middle Marsh			
Acorus calamus	P		
Sagittaria latifolia	P		
Leerzia oryzoides	P		10 cm flooding reduced abundance[8]
Impatiens capensis	A		Flooding reduced germination rate[7]
Polygonum arifolium	A		10 cm flooding reduced abundance[8]
Peltandra virginica	P		**Not** affected by 10 cm flooding[8]
Typha angustifolia	P	Reduced biomass at > 10 ppt[3]	Grows in 1m water, tolerant to flooding[6]
High Marsh			
Acorus calamus	P		
Aster puniceus	P		
Bidens laevis	A/P		Flooding reduced germination rate[7]
Iris versicolor	P		
Lythrum salicaria (non native)	P		
Pilea pumila	A		10 cm flooding reduced abundance[8]
Typha latifolia	P		
Polygonum punctatum	A		Flooding reduced germination rate[7]
Polygonum sagittatum	A		
Hibiscus palustris	P		
Phragmites australis	P	Growth decreased with > salinity[4]	Flooding prevented bud emergence[4]
Rosa palustris	P		
Swamp/High Marsh			
Acer rubrum	P		
Alnus serrulata	P		

*A/P = Annual versus Perennial
*Unless noted otherwise, salinity data from Anderson, Richard R., Russell G. Brown, and Robert D. Rappleye. 1968. Water quality and plant Distribution along the Upper Patuxent River, Maryland. Chesapeake Science 9(3) 145-156.

Of the dominate species listed, arrow arum is the only species with tolerance for flooding. Arrow arum is capable of successful growth in up to 10 cm (4 inches) of flooding. Wild rice exhibits reduced size and seed production when flooded with 30-50 cm (11-20 inches) of water. In Jug Bay there is limited area for marsh migration due to land slope and some residential properties. The marshes could potentially have limited room to move or be forced to compete with existing flood tolerant plants. As a result, less competitive species will be pushed out. This could change the habitat structure to negatively impact the fish, bird, mammal, and invertebrate populations. One positive characteristic regarding the invasive strains of *Phragmites australis* is that *P. australis* has shown the potential to accrete sediment better than the wetland plants it replaces further promoting better marsh elevations to keep pace with sea level rise (Chambers et al. 1999). The dense monocultures of *P. australis* found within the Jug Bay marsh have the potential to help compenstate for rising water levels. But, the fates of the Jug Bay marshes should not be dependent upon *P. australis* domination.

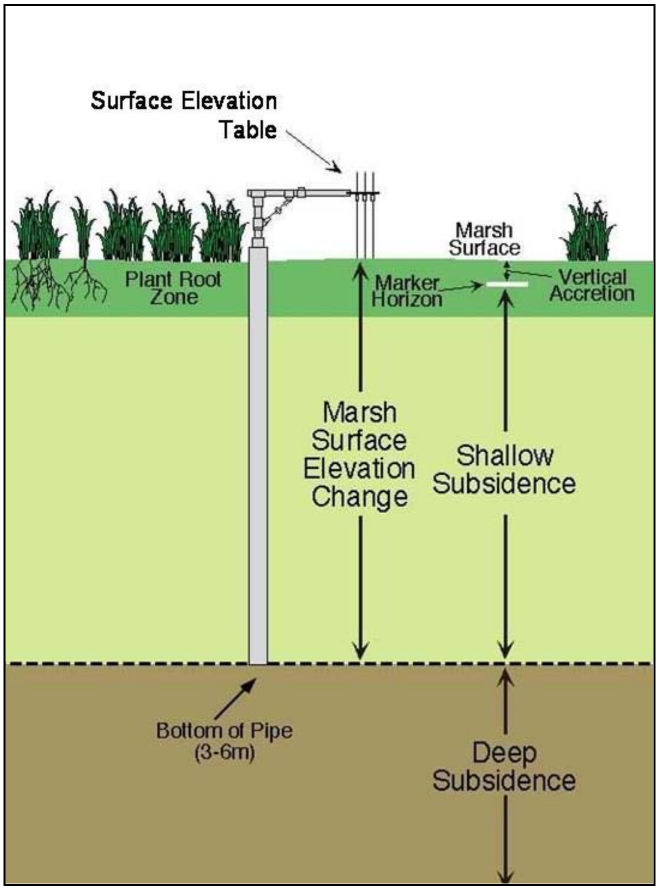
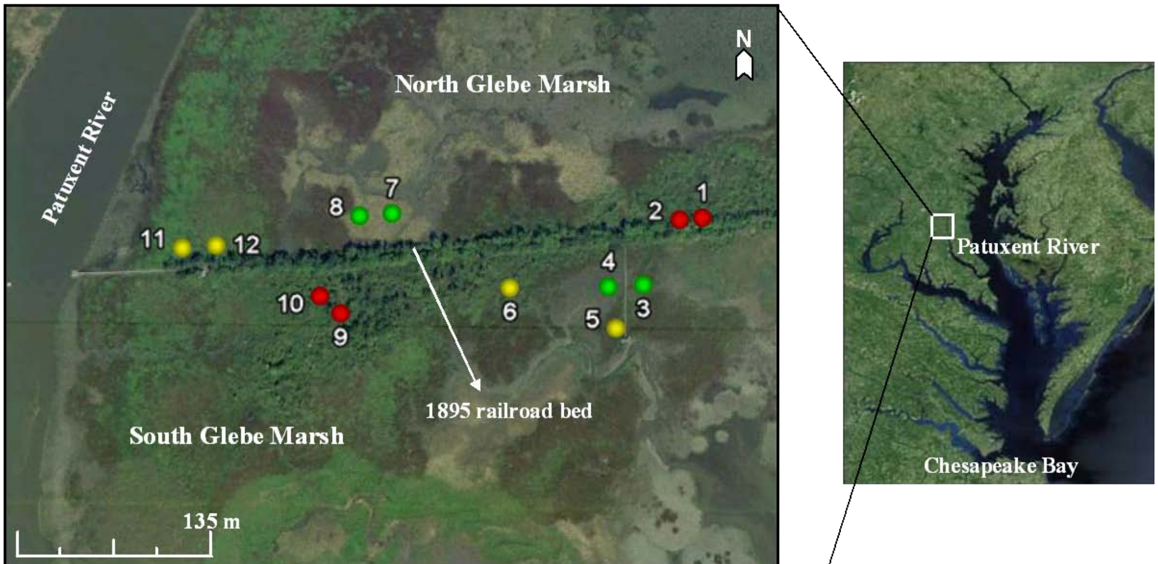


Figure 3.5.7 Diagram illustrating the key characteristics of a Surface Elevation Table (SET), including the factors contributing to surface elevation change. Image: Courtesy of Don Cahoon and Jim Lynch, USGS.

The future of Jug Bay marsh vegetation is linked to the marsh surface elevation dynamics. The accumulation of inorganic sediments and organic matter on the marsh surface could potentially yield enough sediment accumulation to keep up with projected sea level rise. A commonly used technique to measure marsh surface elevation change is through a surface elevation table (SET). SETs provide a valuable mechanism to estimate marsh elevation change because they account for both marsh vertical accretion and land subsidence (Figure 3.5.7).

CBNERR-MD has been monitoring marsh surface elevation change at Jug Bay using twelve SETs that were originally established by Boumans et al. (2002) in February 1999. The SETs were distributed within the low, mid-high and scrub-shrub zones of the north and south Glebe marshes of the old Jug Bay Wetlands Sanctuary railroad bed (Figure 3.5.8). Marsh surface elevation measurements were recorded each summer (or late spring) and winter (or early spring) from July 1999 through July of 2002. In conjunction, marker horizons, used to measure vertical accretion, were established in the summer of 2000 and measured in July of 2002. SET results were presented for both north and south Glebe marshes based on marsh zone (Figure 3.5.9). The low marsh zone was dominated by *Nuphar lutea* spp. *advena* (spatterdock), the mid-high marsh by *Typha* spp., and the highest marsh by scrub-shrub type vegetation. It was apparent through this preliminary study that the scrub-shrub sites had a significant loss in elevation through the study period. The north marsh had an elevation loss of approximately 24.6 ± 6.1 mm/yr while the south marsh had a loss of 12.3 ± 3.4 mm/yr (Boumans et al. 2002).



	North Glebe Marsh	South Glebe Marsh
Scrub-shrub	SET 1-2	SET 9-10
Mid-high marsh	SET 11-12	SET 5-6
Low marsh	SET 7-8	SET 3-4

Figure 3.5.8 Location of surface elevation tables (SETs) along the north and south Glebe marshes at Jug Bay.

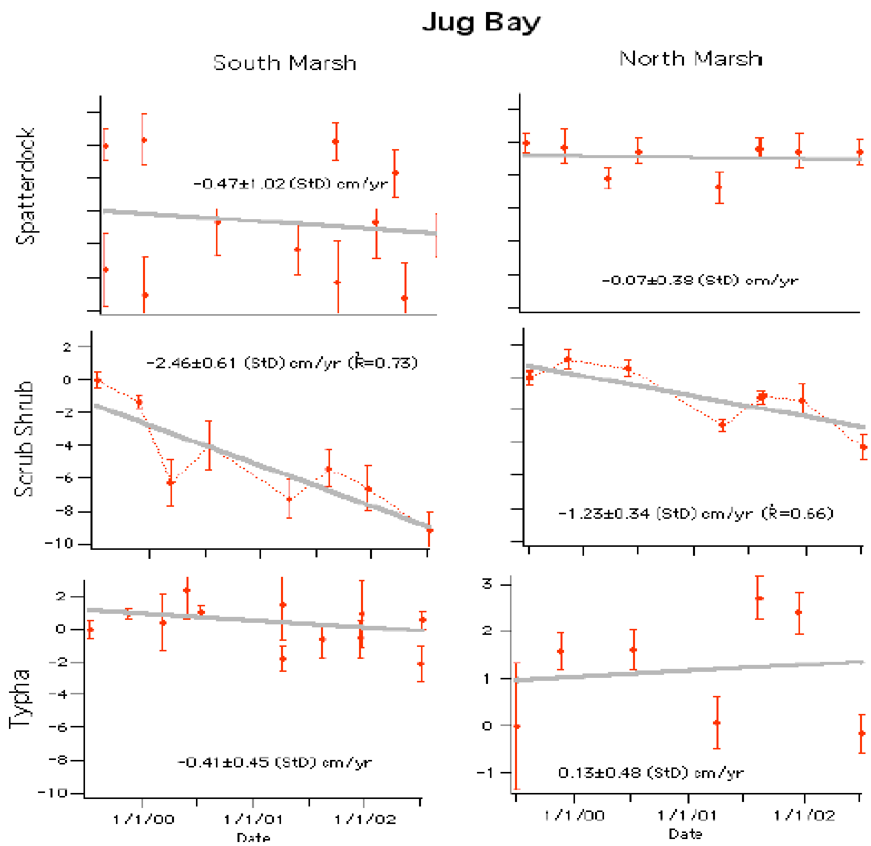


Figure 3.5.9 Figure extrapolated from Boumans et al. 2002 depicting the results from twelve SETs at Jug Bay Railroad Bed. North marsh refers to the north Glebe and South marsh refers to the south Glebe of the Railroad Bed.

After July 2002, elevations were not recorded again until CBNERR-MD started the same seasonal observations in 2007. In 2009, measurements were taken at the beginning of every season instead of the original two seasonal samplings. Three new marker horizons were established at each SET location to replace the older marker horizons. The study was finalized in September of 2009 yielding ten years of long-term surface elevation data and nearly two years of marsh accretion data. Results showed an average marsh surface elevation change of 0.0 $\pm$ 1.6 mm yr^{-1} for the north Glebe marsh and 5.8 $\pm$ 1.6 mm yr^{-1} for the south Glebe marsh. With the average sea level rise mentioned above (3.41 ± 0.29 mm yr^{-1}) it is clear that the south Glebe marsh will keep up with current sea level rise, while the north Glebe marsh will not. The vertical accretion rates were all positive throughout the study, averaging 26 ± 7 mm yr^{-1} and 23 ± 8 mm yr^{-1} for the south and north Glebe marshes, respectively. These data indicate that marsh elevation does not depend on the delivery of sediments and the accumulation of organic matter alone. Postitive vertical accretion values do not always translate to positive surface elevation change. The lower elevation change of the north marsh is likely a result of the alteration of the natural hydrological regime due to the presence of the railroad bed, local subsidence, and decomposition.

In near shore habitats, deepening water reduces sunlight penetration to SAV species further pushing them inward onto existing tidal marsh habitat, assuming substrate is suitable (Shellenbarger 2008). The overall survival of SAV species with the threat of deepening waters and inland transition is yet to be determined by scientists. Therefore, the future of SAV at the Jug Bay component as the effects of sea-level rise occurs is unknown.

Sea level rise will potentially cause salinity shifts within the Chesapeake Bay and its tributaries through the movement of the salt front further upstream. Within tidal freshwater marshes, increases in salinity can cause a shift of marsh vegetation to more salt tolerant species. Consequently, habitat loss or transition will have a direct impact on the growth, reproduction and survival of marsh dependent species, including: fish, bird, invertebrate, and mammal species (Shellenbarger 2008). The average salinity calculated from three continuous monitoring stations within the Jug Bay area is approximately 0.18 ± 0.0005 (Table 3.3.2 of Jug Bay Water Quality section). *Nuphar advena* (spatterdock), *Zizania aquatica* (wild rice), *Peltandra virginica* (arrow arum), and *Pontederia cordata* (pickerelweed) are the most dominant species of the low to mid marshes of the Jug Bay component. As increased sea level drives higher salinities up-river, the freshwater marshes of Jug Bay could transition to more oligohaline to slightly brackish (greater than 0.5 ppt). As a result, spatterdock and wild rice with salinity tolerances of less than 0.4 ppt would suffer (Table 3.5.1). Salinity intolerant species could become salt burned, stunted, grow at reduced rates and/or exhibit reduced carbon assimilation (Scavia et al. 2002). As salt intolerant species suffer, more salt tolerant species will prevail resulting in decreased species diversity. Furthermore, increased salinity can modify the decomposition of organic matter. Salinity intrusion increases the availability of sulfate (SO_4^{2-}). The increased availability of sulfate reduces the methanogenesis pathway further slowing the accretion of marsh sediments; therefore, reducing the potential of the marsh to adapt to sea level rise (Weston et al. 2006).

Alteration in air temperature is also a likely result of impending climate change. The average air temperature of Maryland is expected to increase by 1.6°C (3°F) by 2050 (Boesch et al. 2008). NOAA reported that 2010 tied with 2005 for the warmest global surface temperature years on record since 1880. Whereas Maryland did not have record warm temperatures in 2010, the average temperature was higher than normal (Figure 3.5.10). Most of the contiguous states experienced normal to above normal temperature ranks. Increasing temperatures could result in zonation shifts of wetland species. The USDA and Arbor Day Foundation developed a conceptual diagram of plant hardiness zone shifts based on 1990 and 2006 hardiness zone maps (Figure 2.5.7. of Otter Point Creek Climate Change section). It is apparent that the hardiness zones are shifting northward. Maryland experienced both no zone and a positive one hardiness zone shift. Meaning, several regions in Maryland experienced a complete hardiness zonation shift yielding further evidence of a warming climate. As the climate warms, Jug Bay marsh vegetation with adaptive strategies will respond while temperature sensitive plants will shift.

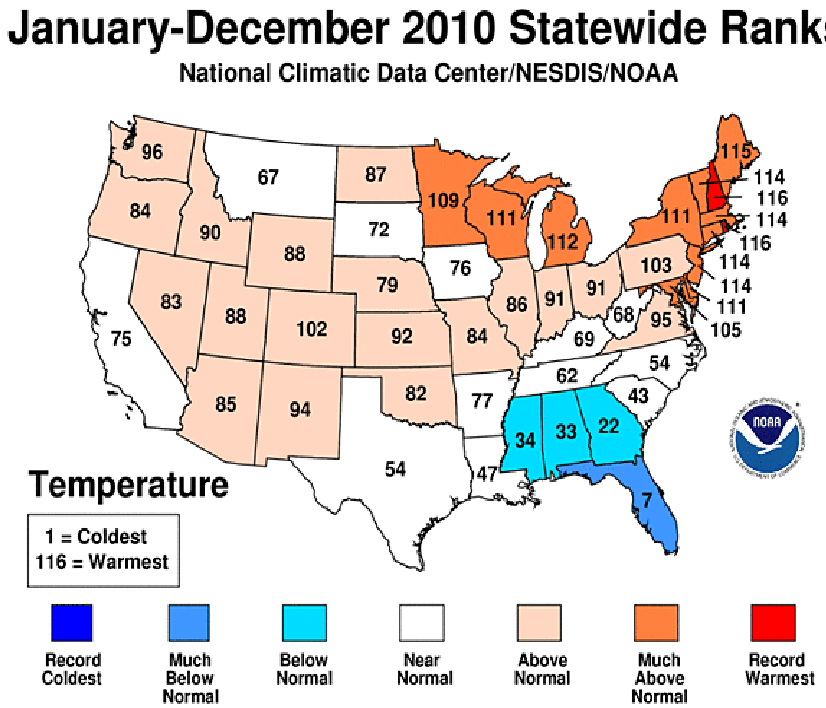


Figure 3.5.10 Statewide temperature ranks for January-December of 2010. National Climatic Data Center, NOAA (2011).

Furthermore, Chesapeake Bay water temperatures have been increasing at a rate of 0.2°C (0.4°F) per decade since 1938 equating to an overall warming of 1.5°C (2.8°F) through 2006 (Figure 2.5.8 of Otter Point Creek Climate Change section). Increases in water temperatures are likely to fuel storm events of greater intensity. Future hurricane frequency and strength for the mid-Atlantic region is unknown. However, it is known that a minimum of 2.2°C (4°F) rise in water temperature will yield 5-10% storm wind strength increases. The combination of higher sea levels and more intense winds make shorelines more vulnerable to erosion (Boesch et al. 2008). Historically, increased sea-water surface temperatures correlated with wet periods within the Chesapeake Bay region and it has been hypothesized that climate variability in the Chesapeake Bay area has a strong link to oceanic factors (Cronin et al. 2000). Lastly, Tester (1996) determined that increases in water temperature will likely affect the species composition, geographic range, and grazing rates of zooplankton on certain phytoplankton species. Specifically, during warmer periods, some toxic phytoplankton prefer wider distributions. Lower concentrations of toxic phytoplankton will yield less toxic algal blooms resulting in positive affects to water quality.

The Global Historical Climatology Network of NOAA ranked 2010 as the wettest year on record in terms of average global precipitation (NCDC 2011). Projections for increases in precipitation are not as clearly determined as they are for temperature. It is expected to be episodic with moderate increases during the winter and spring. With rising temperatures, extended drought periods will be more likely during the summer months (Boesch et al. 2008). Since precipitation rates are uncertain, impacts to the natural hydrological regime are also unknown. Greater precipitation will likely increase stream flow and further increase the accretion potential of wetlands (Najjas et al. 2000). Historically, modified climate factors have caused southern shifts in the polar front and jet stream. When this phenomenon occurs, the east coast of the U.S. has seen greater precipitation events (Cronin et al. 2000). Increased precipitation will increase freshwater inputs and yield greater run-off of sediments and nutrients. Both emergent and underwater vegetation will be forced to adapt. The species that are more tolerant will likely prevail if hydrological shifts are extreme.

CBNERR-MD has been collecting long-term monitoring data on emergent vegetation, SAV, water quality and surface elevation dynamics with the goal of determining the effects of climate change on the tidal freshwater marshes of the Jug Bay component. Fifteen emergent vegetation transects were established in the summer of 2008, and data have been collected every growing season through 2010. Three years of baseline data have been established; therefore, transects will be monitored bi-yearly beginning in 2012. Six SAV transects have been monitored every June, August and, October since June of 2007. The same yearly monitoring methodologies will continue until otherwise determined. Three continuous monitoring stations (CONMON) have been monitoring water quality data since 2003 and have provided CBNERR-MD with very useful data regarding the upper Patuxent River health. The twelve old SETs located at the Railroad Bed will continue to be measured approximately every five years. In March of 2010, twelve new SETs were established alongside existing emergent vegetation transects, six along the low marsh and six within the high marsh. These SETs will be sampled twice a year at the beginning of spring and fall. The goal is to track the surface elevation dynamics and potentially monitor shifts in emergent vegetation. All of these long-term monitoring efforts will yield large datasets that contribute to the Climate Change Sentinel Site network established by the National Estuarine Reserve System. The sentinel site data from all Reserves will provide crucial information regarding the impacts of climate change on essential coastal ecosystems. These findings will provide mechanisms to affect policies and future decision making regarding threats of climate change.

3.5.2.3 Invasive Species

Invasive species have become increasingly problematic because of their tendencies to proliferate quickly and to displace native species. There are 55 known introduced and/or invasive species that have been characterized through species lists provided by the Jug Bay Wetlands Sanctuary (Table 3.5.2). Of the many of the species that have been introduced to the Sanctuary, some of the more problematic include *Lythrum salicaria* (purple loosestrife), *Phragmites australis* (common reed), and *Hydrilla verticillata* (hydrilla).

Table 3.5.2 Non-Native Species of Jug Bay.

Order	Family	Scientific Name	Common Name	Status
BIRDS				
Anseriformes	Anatidae	*Cygnus olor*	Mute swan	R
		Branta canadensis	Canada goose (resident)*	P
Columbiformes	Columbidae	*Columba livia*	Rock dove	R
Passerformes	Passeridae	*Sturnus vulgaris*	European starling	P
		Passer domesticus	House sparrow	R
MAMMALS				
Rodentia	Echimyidae	*Myocastor coypus*	Nutria	R
	Muridae	*Rattus norvegicus*	Norway rat	R
REPTILES				
Testudines	Emydidae	*Trachemys scripta elegans*	Red-eared slider	P
FISH				
Cypriniformes	Cyprinidae	*Carassius auratus*	Goldfish	A
		Cyprinus carpio	Common carp	A
		Pimephales promelas	Fathead minnow	R
Perciformes	Centrarchidae	*Lepomis macrochirus*	Bluegill	P
		Micropterus dolomieu	Smallmouth bass	R
		Micropterus salmoides	Largemouth bass	P
		Pomoxis annularis	White crappie	R
		Pomoxis nigromaculatus	Black crappie	R
Siluriformes	Ictaluridae	*Ictalurus punctatus*	Channel catfish	P
WOODY PLANTS				
Fabales	Fabaceae	*Albizia julibrissin*	Mimosa	P
Sapindales	Simaroubaceae	*Ailanthus altissima*	Tree of heaven	A
Fagales	Fagaceae	*Castanea mollissima*	Chinese chestnut	P
Cornales	Cornaceae	*Cornus kousa*	Japanese dogwood	
Scrophulariales	Scrophulariaceae	*Paulownia tomentosa*	Princess tree	R
Rosales	Rosaceae	*Pyrus calleryana*	Bradford pear	R
HERBACEOUS PLANTS				
Apiales	Araliaceae	*Hedera helix*	English ivy	R
Asterales	Asteraceae	*Cirsium arvense*	Canada thistle	P
Capparales	Brassicaceae	*Alliaria petiolata*	Garlic mustard	A
		Cardamine hirsuta	Hairy bittercress	P
Caryophyllales	Caryophyllaceae	*Dianthus armeria*	Deptford pink	P
		Stellaria media	Common chickweed	P
Celastrales	Celastraceae	*Celastrus orbiculatus*	Oriental bittersweet	P
Commelinales	Commelinaceae	*Murdannia keisak*	Swamp dayflower	P
Cyperales	Poaceae	*Microstegium vimineum*	Japanese stiltgrass	A
		Phragmites australis	Common reed	P
		Setaria faberi	Japanese bristlegrass	R
Dipsacales	Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle	A
Fabales	Fabaceae	*Coronilla varia*	Crown vetch	P
		Lespedeza cuneata	Chinese lespedeza	P
Lamiales	Lamiaceae	*Glechoma hederacea*	Gill over the ground	P
		Perilla frutescens	Beefsteak plant	R
Liliales	Liliaceae	*Hemerocallis fulva*	Orange daylily	P
Myrtales	Lythraceae	*Lythrum salicaria*	Purple loosestrife	P

Order	Family	Scientific Name	Common Name	Status
Polygonales	Polygonaceae	*Polygonum cuspidatum*	Japanese knotweed	R
		Polygonum hydropiper	Water pepper	P
		Persicaria perfoliatum	Mile-a-minute weed	P
Ranunculales	Berberidaceae	*Berberis thunbergii*	Japanese barberry	
Rhamnales	Vitaceae	*Ampelopsis brevipedunculata*	Porcelainberry	P
Rosales	Rosaceae	*Duchesnea indica*	Indian strawberry	P
		Rosa multiflora	Multiflora rose	P
		Rubus phoenicolasius	Wineberry	P
Scrophulariales	Oleaceae	*Ligustrum* sp.	Privets	P
	Scrophulariaceae	*Verbascum thapsus*	Wooly mullein	P
Urticales	Moraceae	*Morus alba*	White mulberry	R
SUBMERGED AQUATIC VEGETATION				
Alismatales	Potamogetonaceae	*Potamogeton crispus*	Curly pondweed	P
Hydrocharitales	Hydrocharitaceae	*Hydrilla verticillata*	Hydrilla	A
Najadales	Najadaceae	*Najas minor*	Brittle waternymph/ Spiny naiad	A
Key: A = Abundant; P = Present; R = Rare; U = Unknown				

* The resident subspecies of Canada goose present at Jug Bay year-round are non-native and invasive while the migratory Hudson Bay populations present only from October through April are not.

This list was compiled utilizing species lists organized by the Jug Bay Wetlands Sanctuary. Editorial contributions were made by Chris Swarth and Lindsay Hollister of the JBWS and Kerry Wixted of the Maryland Department of Natural Resources.

***Lythrum salicaria* (purple loosestrife)**

Lythrum salicaria (purple loosestrife) is an herbaceous plant that is indigenous to Eurasia and first appeared in the United States in 1814. Its monotypic stands cause habitat degradation and reduce biotic diversity through crowding out native plant species (Malecki 1993). In the Jug Bay Reserve, it is found in the tidal freshwater marshes ranging from Western Branch to Mataponi Creek. CBNERR-MD has actively monitored purple loosestrife since 2007 through 15 vegetation transects located within the Jug Bay Reserve. Baseline data have been collected for three years. Current plans call for bi-yearly monitoring beginning in 2012. In 2011, CBNERR-MD mapped the purple loosestrife stands along the Patuxent River extending from Western Branch to Mataponi Creek.

Collaborative efforts to help control the spread of purple loosestrife in the Reserve began in 2007. CBNERR-MD staff initiated mechanical removal in Western Branch during the summer of 2007. In 2008, CBNERR-MD partnered with the Minority Student Summer Conservation Work-Study Program of the National Aquarium in Baltimore to remove purple loosestrife from locations within both Western Branch and Mataponi Creek. The program allowed undergraduate students to gain awareness of purple loosestrife and its threats to Jug Bay marshes as well as gain experience in mechanical removal and restoration. Also in 2008 and again in 2009, students from the Patuxent River Teen Paddle assisted with mechanical removal from Mataponi Creek. In 2010, CBNERR-MD staff initiated the first chemical spray effort; plants were spot sprayed at several locations in Western Branch. Also in 2010, Jug Bay Wetlands Sanctuary Volunteer Coordinator organized a mechanical removal project with volunteers where 27 trash bags of purple loosestrife were removed from Western Branch. Both Jug Bay Wetlands Sanctuary and Patuxent River Park will participate in ongoing volunteer-driven removal.

***Phragmites australis* (common reed)**

Phragmites is common in brackish and freshwater marshes and its status of native or invasive to the U.S. has been the subject of debate for years. Fossil records of *Phragmites* in North America date back to the Cretaceous period. It has not been until the last 200 years that the relative abundance of *Phragmites* has shifted (Chambers et al. 1999). Some research supports that the shift in *Phragmites* density trends were due to the introduction of genetic variants. Bestika (1996) suggests that the tetraploid variant was introduced to the U.S. via the trans-Atlantic shipping industry and has thence become the most aggressive variant. *Phragmites* is problematic because it has the ability to colonize in highly disturbed areas and aggressively spread vegetatively through rhizome root systems. These root systems create dense monocultures that shade out native plant communities, reduce biodiversity and negatively impact wildlife (Rice et al. 2000). CBNERR-MD has actively monitored *Phragmites* since 2007 through 15 vegetation transects located within the Jug Bay component. Baseline data have been collected for three years; therefore, bi-yearly monitoring will begin in 2012.

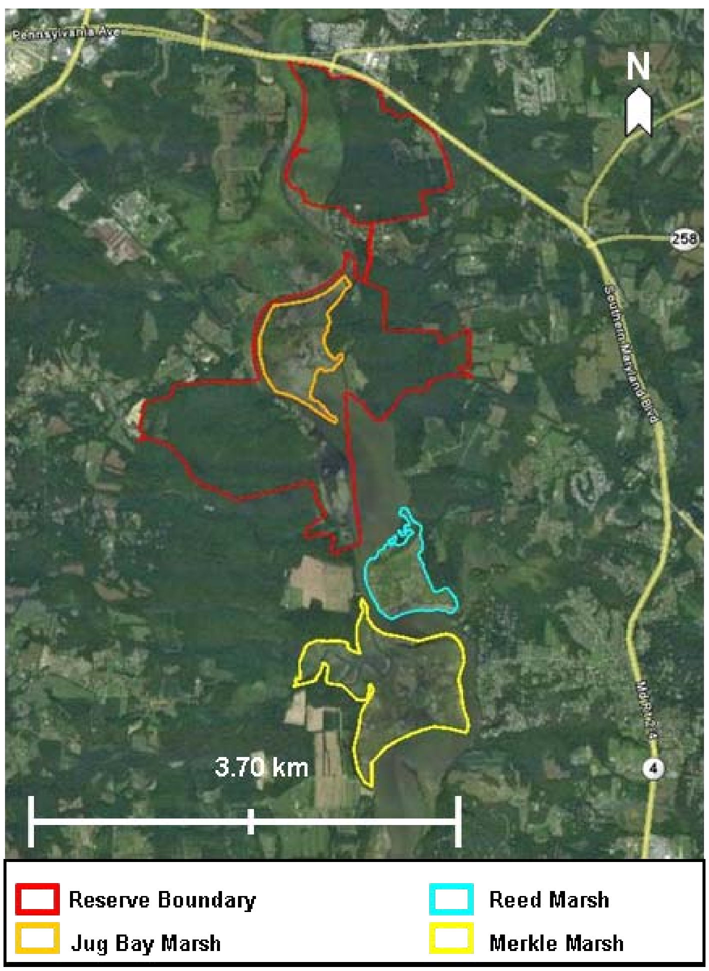


Figure 3.5.11 Location of Jug Bay, Reed, and Merkle marshes in relation to the Jug Bay Reserve Boundary.

Rice et al. (2000) summarized the presence of *Phragmites* in three freshwater marshes of the upper Patuxent River. The marshes include Jug Bay marsh, which is located inside Reserve boundaries, and Reed and Merkle marshes, which are located just outside Reserve boundaries (Figure 3.5.11). Based on the analysis of aerial photographs, *Phragmites* has been present in all three freshwater marshes prior to 1938. Intrinsic increases in stand coverage have been quantified from aerial photographs from 1938, 1971, 1985, and 1994 (Table 3.5.3). Jug Bay marsh had lower percent coverage of stands compared to Reed and Merkle marshes. Reed marsh has had consistently high intrinsic rates of increase compared to Merkle and Jug Bay marshes.

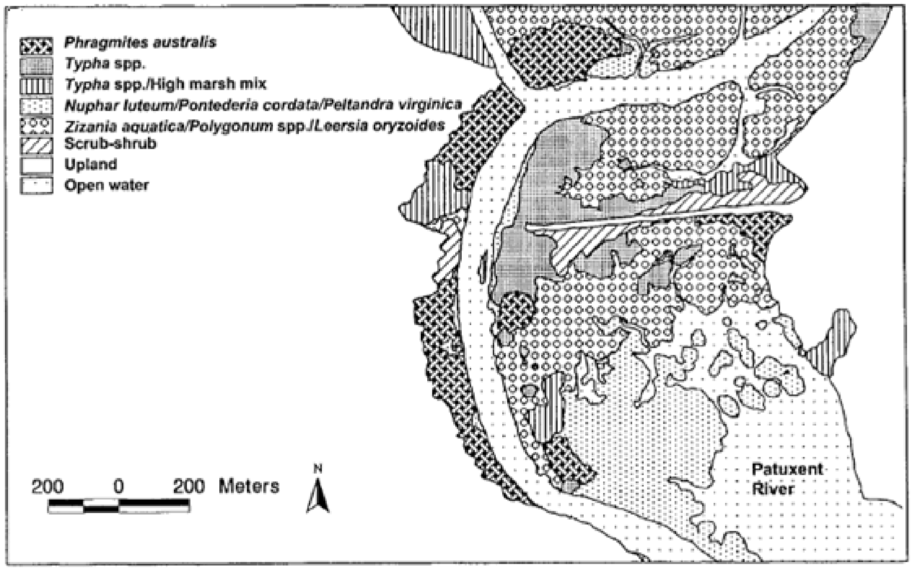
Table 3.5.3 Total area (m^2) and intrinsic rate of increase of *Phragmites australis* stands in three freshwater marshes of the upper Patuxent River.

					Intrinsic Rate of Increase (per year)		
Marsh	1938 Total area (m^2) % of marsh	1971 Total area (m^2) % of marsh	1985 Total area (m^2) % of marsh	1994 Total area (m^2) % of marsh	1938-1971	1971-1985	1985-1994
Jug Bay	62,039 2.50%	112,625 4.54%	147,244 5.93%	157,507 6.35%	0.0181	0.0191	0.0075
Reed	173,397 15.55%	305,735 27.41%	381,131 34.17%	428,114 38.38%	0.0172	0.0157	0.0129
Merkle	216,634 10.81%	426,396 21.57%	449,112 22.72%	474,928 24.02%	0.0209	0.0037	0.0062

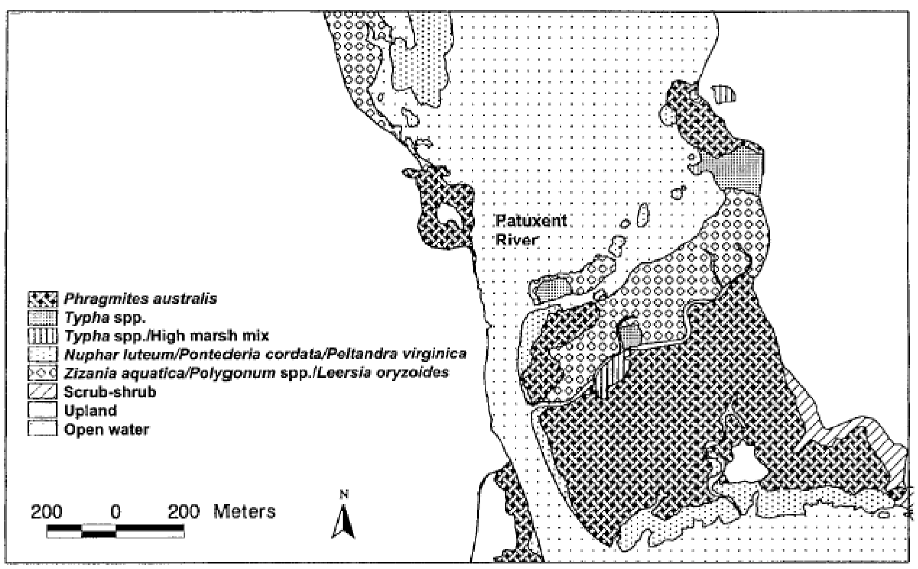
*Values were extrapolated from a table found in Rice et al. (2000).

As of 1994, *Phragmites* covered 6.35% of Jug Bay marsh, 38.38% of Reed marsh, and 24.02% of Merkle marsh (Figure 3.5.12). While Reed and Merkle marshes are just outside Reserve boundaries, the spread of *Phragmites* within these areas through wind pollination has potential to affect marshes inside Reserve boundaries.

(A). Jug Bay marsh



(B.) Reed marsh



(C) Merkle marsh

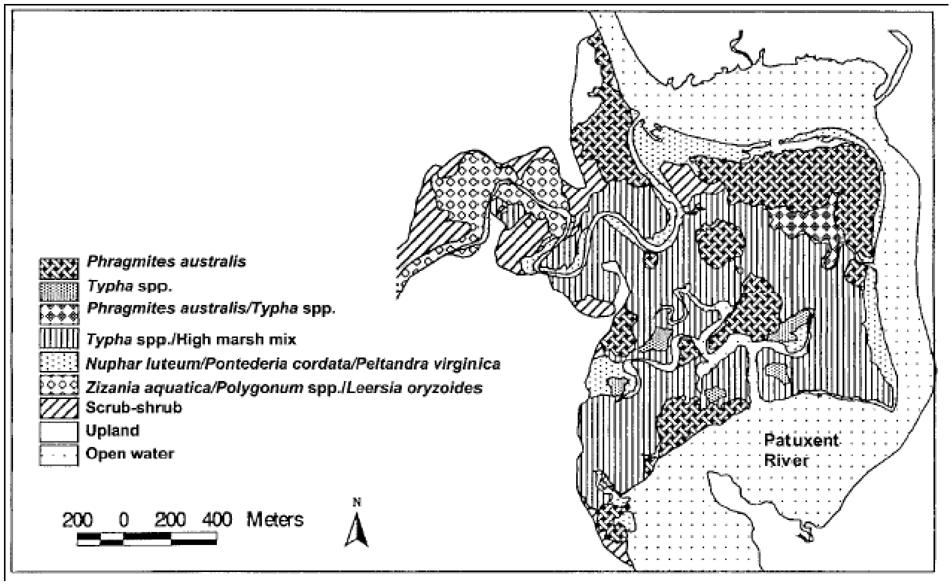


Figure 3.5.12 Aerial photographs from 1994 extrapolated from Rice et al. (2000) characterizing *Phragmites australis* stands in (A.) Jug Bay, (B.) Reed, and (C.) Merkle marshes.

Phragmites has also proven to be a sediment stabilizer and a potential sink for nutrients from wastewater. The complex rhizomes stabilize sediment and have greater potential to vertically accrete minerals and organic matter in tidal marshes susceptible to sea-level rise compared to the wetland plants *Phragmites* replaces (Chambers et al. 1999). Furthermore, the rhizomal roots extend up to 1.5 meters (5 ft) down into marsh substrate forming a dense, but very active rhizosphere. Although quantification of wastewater treatment in natural wetlands is highly variable, artificial wetlands containing *Phragmites* have proven to successfully remove suspended solids, nitrogen, and phosphorus. As the wastewater passed through the rhizosphere, nitrogen was denitrified by bacteria while phosphorus and heavy metals bound to the soil further yielding an effluent equivalent to advanced secondary treatment quality (Brix and Schierup 1989). The wastewater treatment capabilities of *Phragmites* have potential for seasonal benefits to the marshes of Jug Bay located next to the Western Branch Wastewater Treatment Plant by cleaning nutrients from the water.

There have been two chemical herbicide application efforts to control the spread of *Phragmites* in marshes within and nearby Reserve boundaries. Patuxent River Park Naturalist, Greg Kearns collaborated with Donald Webster of the Wildlife and Heritage Unit of the Maryland Department of Natural Resources in chemical control via helicopter. The first application of the herbicide, Aquastar, was to 200 acres of marsh on October 2, 2000 and the second application was to 180 acres of marsh on October 4, 2004. Total acreage of *Phragmites* sprayed includes locations that were sprayed during both applications (Figure 3.5.13). In 2001, the “drop burn” method was initiated to supplement the herbicide spray. It was only successful in the Merkle Marsh due to the high density of stalk material. The herbicide spray of the monocultures was very successful and the combination of methods had even greater success in locations with dense stalks. There are currently no future plans for chemical application of herbicide or “drop burning;” however, there is an interest to apply the same methodologies when funding permits (Greg Kearns, pers. comm., 2010).

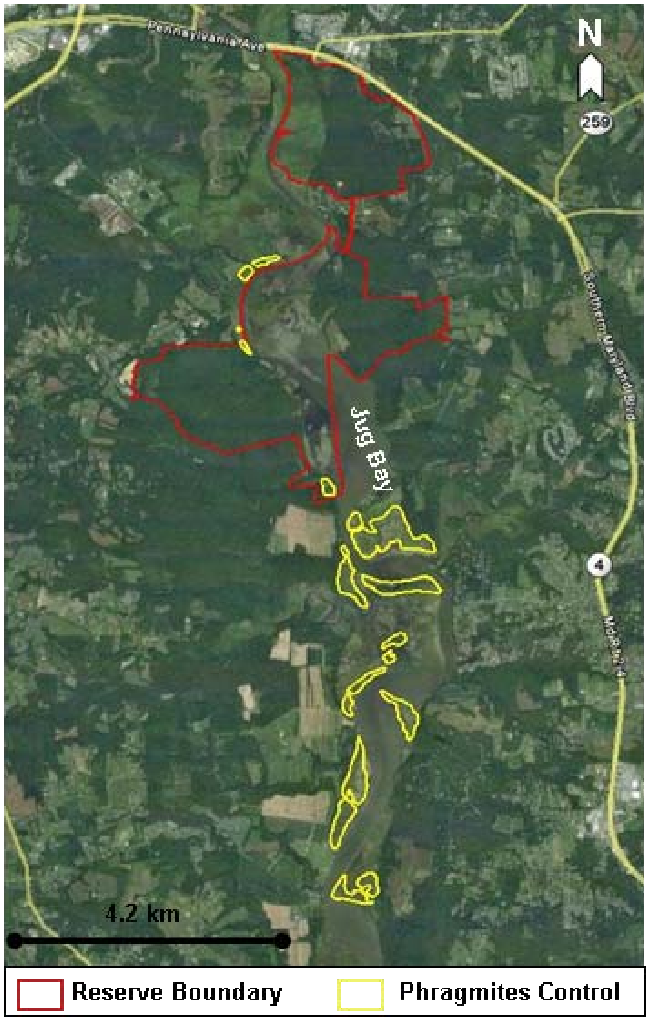


Figure 3.5.13 Locations within the Patuxent River estuary where herbicide was applied in 2000 and 2004 to control *Phragmites australis* (common reed).

Hydrilla verticillata **(hydrilla)**
Hydrilla (*Hydrilla verticillata*) is an underwater plant invader native to countries surrounding the Indian Ocean. In August of 1980, four scientists identified hydrilla while wading in the reflecting pool in our Nation’s Capital. It had been planted by the National Park Service who mistakenly identified it as the native species *Elodea canadensis* (Fincham 2009). It was found thriving in the Potomac River in 1983 and first discovered by Maryland-National Capital Park and Planning Commission, Patuxent River Park personnel, in Back Channel and Mill Creek in 1993. Both Back Channel and Mill Creek are freshwater tributaries of the Patuxent River located north of Jug Bay compoents boundaries.

Naylor and Kazyak (1995) characterized the SAV biomass among the tidal freshwater stem and tributaries of the Patuxent River from 1 June to 3 October, 1994. Their sampling stations included Back Channel and Mill Creek as well as numerous other stations located within Reserve boundaries (Figure 3.5.14). During their 1994 sampling season, hydrilla was one of 11 different species identified. Hydrilla was the only species to exhibit an overall increase by percentage of total species biomass during the sampling period (Figure 3.5.15a). Hydrilla increased from 1% of all species in June, to 25% in July, and finally became 43% of all species in September. Its distribution increased from two stations in June to seven stations by September (Figure 3.5.15b). Where it was first found in Back Channel, it increased from 20% of total biomass in June, to 88% in July, to 98% of total biomass in September (Figure 3.5.16). Thenceforth, CBNERR-MD has been monitoring SAV biomass at six sites along the upper sections and Jug Bay region of the Patuxent River since 2007. Thus far, hydrilla has been the most dominant species among the eight species found. The combination of SAV biomass estimations concluded from CBNERR-MD and the 1994 sampling done by Naylor and Kazyak will provide a valuable mechanism for tracking the trends in hydrilla dominance within the Reserve. The Reserve staff and partners do not currently have control efforts or removal plans intact for hydrilla. While hydrilla has invasive characteristics, the patches within the Reserve have not made the Patuxent non-navigable for boaters as it has in many regions of the Potomac. In the Patuxent, the mats are successfully increasing water clarity, aiding in nutrient uptake, providing food for waterfowl and shelter and habitat for fish (Friebele et al. 2001).

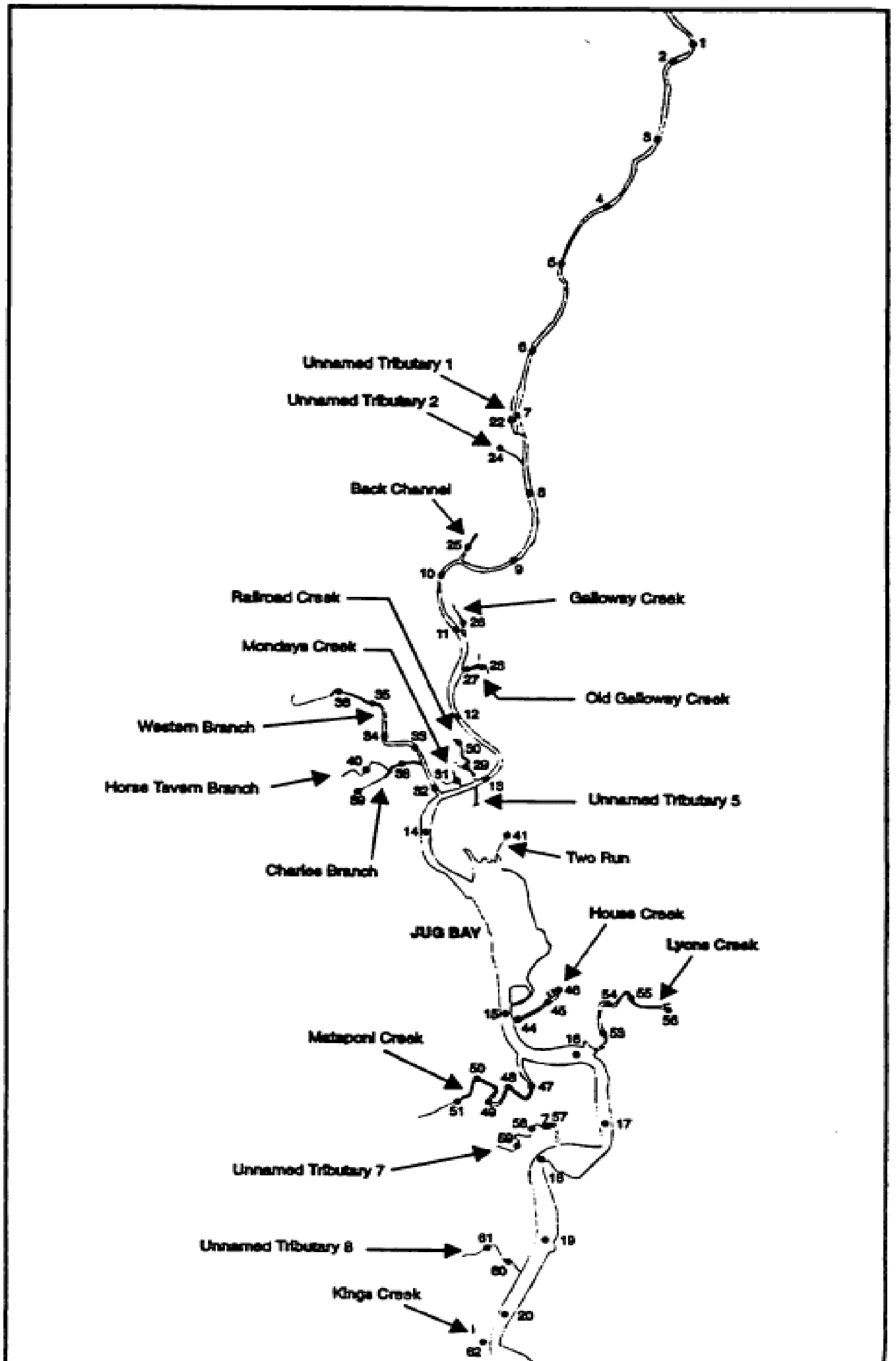


Figure 3.5.14 Map of submerged aquatic vegetation sampling stations extrapolated from Naylor and Kazyak (1995).

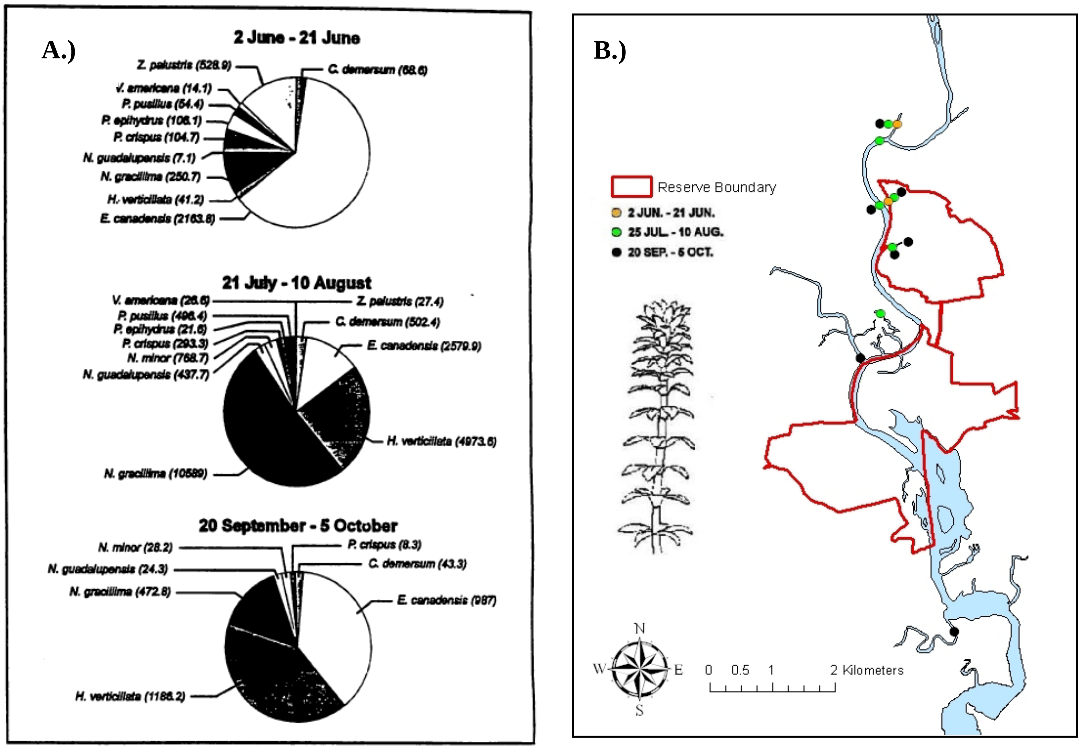


Figure 3.5.15 (A.) Submerged aquatic vegetation biomass (g) by species in the tidal freshwater region of the Patuxent River for the 1994 sampling season of June-October (figure extrapolated from Naylor and Kazyak (1995); (B.) map indicating *Hydrilla verticillata* presence from the 1994 sampling season with Jug Bay Reserve boundary (data extrapolated from Naylor and Kazyak 1995).

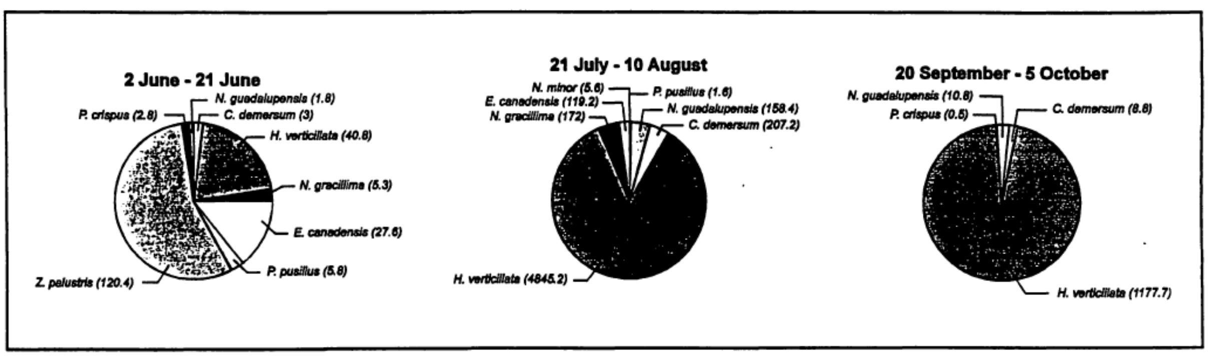


Figure 3.5.16 Submerged aquatic vegetation biomass (g) by species in Back Channel, the tributary of the Patuxent River where *Hydrilla* was first identified. Figure extrapolated from Naylor and Kazyak (1995).

Purple loosestrife, *Phragmites*, and hydrilla are not the only species invading the marshes and open water areas of the tidal Patuxent River. Invasive species will continue to be a problem until extensive measures are taken by boaters and surrounding citizens to ensure minimal transport of seeds and/or other reproductive materials into other systems. Furthermore, education and outreach is necessary to inform individuals of invasive species characteristics and provide mechanisms for how assistance can be given to reduce the problem.

3.6 Research and Monitoring

The Jug Bay component is by far the most studied site in CBNERR-MD. The wealth of information available for Jug Bay ranges from water quality, nutrient cycling and budgets to marsh ecology as well as the study of various wildlife groups and aquatic organisms. All these have been the result of decades of studies conducted by scientists from universities and other research institutions as well as researchers from federal, state, and local government organizations. In addition, the Reserve's research program – in conjunction with its Graduate Research Fellowship program – has initiated, conducted, and supported a series of research and longterm monitoring projects since the establishment of this component. Despite all progress, there are still many unanswered questions. Addressing these questions will help to better characterize and understand the status, functioning, and responses to impacts and environmental change of Jug Bay's many natural communities. It will also support a more science-driven approach to management, protection, and/or restoration of this component's aquatic resources.

Potential research and monitoring initiatives at the Reserve should fulfill information needs for the greater Jug Bay area. These initiatives should follow the short and long-term goals and objectives specified in the Reserve's research and monitoring plan and management plan. They should also consider the needs of the Reserve's partners, Patuxent River Park (PRP) and Jug Bay Wetlands Sanctuary (JBWS), as indicated in their respective management plans. At the national scale, research and monitoring efforts will follow initiatives guided by the NOAA-National Estuarine Research Reserve System. A means to better direct and target research projects within Jug Bay is to make use of the existing JBWS Science Advisory Committee (SAC). Its members represent key science departments at major universities as well as the Smithsonian Environmental Research Center (SERC); the Reserve's Research Coordinator is also a member of this Committee. Overall, the SAC engages in several activities:

- Advises JBWS staff on its overall Research Program
- Reviews research proposals, reports, publications and abstracts for conferences
- Promotes JBWS as a field laboratory
- Provides expertise for selected projects
- Advises Reserve's research staff on proposed research and monitoring projects

Because of current limited availability of resources for natural science research, the implementation of most new research and monitoring efforts would entail coordination and collaboration with existing and new partners. The Reserve's Research program will actively engage with academic and other research institutions to foment their interest in conducting projects that will address Jug Bay research needs. Volunteers have always played an important role in the collection of field data, particularly as part of monitoring projects. This relationship would be strengthened by providing more opportunities for training, direct involvement with the planning, collection, and analysis of data, and delivery of information to appropriate audiences.

In an effort to increase available resources to conduct research within the Reserve and adjacent watersheds, the Research program will pursue available grants in collaboration with partners. The NERRS Graduate Research Fellowship program provides opportunities to address research needs within the Reserve by appointing a year-long research fellow in the Reserve.

3.6.1 Research Facilities

Because of the Reserve's partnership with PRP (Prince Georges County) and JBWS (Anne Arundel County), the research program has access to various facilities and equipment at these two locations that can be used to successfully implement the program's research and monitoring activities. Some of the facilities and equipment available include meeting space, laboratory space, storage areas, water access facilities such as piers and ramps, boats and motors, canoes, and kayaks. In addition, the Plummer House in the JBWS offers office space (with available wireless connection) for CBNERR-MD staff.

3.6.2 Research and Monitoring Needs

Research and monitoring needs for the Jug Bay component listed in this section were identified based on different sources including the CBNERR-MD management plan, reports and peer review papers highlighting information gaps, informal conversations with state staff and other researchers working in this area, and recommendations from Reserve's research program staff based on their on-site knowledge. However, to develop a more comprehensive list of research and monitoring needs for Jug Bay, the CBNERR-MD research staff anticipates planning in 2012 a workshop with Reserve staff, partners, local resource managers, academia, and other interested parties to identify and prioritize research and monitoring needs that would address priority management needs within this region.

Currently, overall research and monitoring activities at Jug Bay will continue to assess the current ecological state of Jug Bay's natural resources as well as changes over time due to the impact of land use and land use changes, management decisions and restoration activities, and climate change, particularly sea level rise. The current approach to address these issues is the continuation of in-place longterm monitoring projects, including water quality, SAV, emergent vegetation, and marsh surface elevation dynamics monitoring. Expansion of monitoring efforts will be considered to involve riparian and terrestrial habitats and to include new sampling sites within impacted watersheds as necessary and as resources become available. In addition, an increase in the understanding of the ecology and interactions among the different plant and animal communities found in Jug Bay is still needed. A description of main research needs organized by biological component is presented in the following sections.

3.6.2.1 Tidal freshwater marshes

Some research and monitoring is already underway to characterize and monitor Jug Bay tidal freshwater marshes and their response to climate change, development, and land use. There are still, however, information gaps that would be important to explore in more detail. Some of these include the development of vulnerability assessments of key marsh species (e.g., wild rice, spatterdock, cattail) to climate change, particularly sea level rise as this may translate into increased salinity levels and flooding. Related to ongoing marsh surface elevation change studies, it is also important to better study and understand marsh migration processes to uplands, potential barriers, as well as spatial and temporal plant and sediment changes as a response to a changing environment.

More studies to assess the presence, concentration, and trapping of heavy metals and toxic elements in marsh sediments as well as their impacts to aquatic organisms are also necessary, particularly in the Mataponi Creek area, where contamination has already been reported.

More information is needed to determine the past, current status, and potential expansion of invasive species at Jug Bay, particularly common reed and purple loosestrife; both of which seem to have expanded during the past years. This project would probably involve field surveying and the analysis of available aerial photography or other available imagery. To complement the project a characterization of the environment where these species are found would be important.

At a broader scale, the development of GIS projects, particularly habitat mapping and change analyses, will be vital for determining the impact of development and land use changes on Jug Bay aquatic and upland resources. Additionally, analyses of aerial imagery involving shoreline movement would provide information on erosion and or expansion of the tidal creek network of this estuarine system.

In addition to ongoing monitoring efforts to track species composition, change, and cover, more research is needed to study the population dynamics of the submerged aquatic vegetation communities at Jug Bay, particularly regarding their role in sediment retention (e.g., hydrilla), nutrient cycling, water quality, and as nursery habitat, and a food source. In the case of the invasive species hydrilla, it is important to better understand its competitive interaction with native species, particularly as it affects the establishment and expansion of existing native species beds.

3.6.2.2 Upland vegetation community

Information available on the local Jug Bay's upland vegetation community is somewhat limited. More information would be welcome regarding their function particularly under projected environmental and climatic changes, for example, carbon sequestration, primary productivity, nutrient cycling, and natural regeneration.

Similarly to other forested areas around Maryland, Jug Bay's upland communities are being impacted by the introduction and expansion of invasive species. How severe and the effects of the longterm impacts of these invasive species in these communities is not well quantified. Also, in order to manage for species diversity and to preserve the characteristic biota of the Jug Bay component, it is important to continue existing monitoring efforts. These efforts include detecting new invasions from non-native species as well as the appearance of new species that may result from expanding distributional ranges resulting from climate change.

Jug Bay volunteers monitor Jug Bay's vernal pools physical properties (e.g., water quality) and the populations of some key vernal pool organisms (e.g., frogs and salamanders). In addition, there is a need to conduct more concrete studies on vernal pools. Needed information may include a more detailed spatial and temporal characterization of their hydrological cycle, soil properties, associated plant community, and their specific role as habitat and reproductive sites for various organisms. Considering how sensitive vernal pools may be to climatic changes, it is important to develop a consistent long-term monitoring plan that would allow for the detection of community changes.

3.6.2.3 Microbiological components

Almost any research and/or monitoring effort to study the microbial communities within Jug Bay, particularly its wetlands, would be a new addition to existing information on these communities. Current water quality monitoring efforts conducted by the Reserve do not include the sampling of fecal coliforms; considering the health issues associated with their presence, it would be an important component to add to the suite of parameters currently being monitored.

Considering predicted climatic changes, it would be important to determine how changes in precipitation patterns, intense drought conditions, and changes in salinity may impact the populations of bacteria in the water and sediments of a tidal freshwater system like Jug Bay.

3.6.2.4 Plankton

Although considerable information is available about the plankton communities of different areas of the Chesapeake Bay, not much is known about the particular communities within Jug Bay, particularly because this is a tidal freshwater marsh and plankton communities in these environments are not as studied as their counterparts in saltier systems. Basic studies are much needed to determine the species composition, abundance, biomass, and productivity of the phytoplankton and zooplankton communities in this area. Further research is also needed to determine the interrelationships between Jug Bay's plankton components and water quality, physical and chemical environmental factors, and the local food web.

Even though a volunteer effort to study plankton has recently started in Jug Bay, it is somewhat limited and it would be useful to increase its spatial and temporal sampling effort as well as its scope. In addition to gathering basic information on plankton species composition and abundance, it would be important to monitor these communities to determine species shifts due to invasive species and to evaluate responses to potential climate and land use changes. Monitoring of potentially harmful phytoplankton species is of particular interest, especially in a eutrophic system like Jug Bay. Topics of interest include how phytoplankton community structure and distribution changes as a result of varying levels of nutrient concentrations; modeling the effects of changes in water column nutrient concentrations on phytoplankton blooms is one approach to help determine this.

3.6.2.5 Macroinvertebrates

The benthic community of Jug Bay has not been the focus of much research. A first priority is to conduct a comprehensive baseline characterization including species composition and abundance in different substrates and habitats within the estuary. Aquatic insects and benthic invertebrates constitute food supply for waterfowl and there is limited knowledge of what is there or their relative abundances.

Conducting studies in both the marsh and open water is important to determine natural spatial and temporal population changes and to evaluate the potential responses to anthropogenic and natural stressors. Of major importance in this area are the potential impacts from eutrophication. Monitoring these communities is also valuable to detect the presence of invasive species and community shifts as a response to climate change. Studies to assess benthic macroinvertebrate communities in non-tidal waters are also important and could be used as an early sign of water quality deterioration in the watershed.

3.6.2.6 Fish, reptiles, and amphibians

The tidal freshwater marshes of Jug Bay provide important habitat for many different species of fish, including some of economic importance for the region such as white perch, croaker, and striped bass. Through the years, a wealth of information has been generated regarding the distribution and ecology of Patuxent River fish communities; less so, however, is particularly focused on the Jug Bay area.

Of particular interest to Jug Bay is to study specific interactions between key fish species and various estuarine habitats, their role within the foodweb, and population responses to natural and anthropogenic impacts including poor water quality, heavy metal contamination, and climate change. How the reproductive cycle and development of fish species (particularly those of economic and high ecological value) as well as their migration and feeding patterns would be impacted by changes in salinity and water temperature are research needs of interest due to current climate change scenarios. In addition, more information would be helpful regarding the potential impacts of commercial and recreational fishing on Jug Bay fish stocks and their collateral damage to other aquatic species.

Although the study on the distribution, nesting behavior, diet, habitat use, and mortality of various turtle species at Jug Bay has been the focus of several studies, more information could be learned from this group including responses to climate change and other environmental pressures. Additional research should include the study of other reptiles and amphibians (including snakes, salamanders, and frogs and toads) found at different Jug Bay habitats, including the vernal pools. Projects may include the study of population dynamics, habitat use, and feeding habits.

3.6.2.7 Birds and mammals

Different bird groups and species have been monitored and studied for many years at Jug Bay; however, there is a need for more information regarding mammal species. Additional studies on this group would add to the natural history of the site. How different species of mammals make use of the wetlands and other habitats, which are their food sources, habits, population sizes, and their responses to a changing environment are areas of research that need more exploration for Jug Bay populations.

Regarding mammals, of particular interest for research and/or monitoring are populations of beavers. Learning more about beavers, their population density, feeding habits, and habitat use is important as they seem to play an important role in the local wetland hydrology. Similarly, learning more about muskrats and their role on marsh vegetation is needed to better understand their potential impact in marsh dynamics. Development of studies to learn more about the least common species of mammals would also enrich the knowledge of Jug Bay's wildlife.

As a response to the deer hunting control effort that started in 2010 at Jug Bay, more information would be needed to better determine the impact of this effort on the recovery of the woodland vegetation in this natural area.

3.6.2.8 Other research and monitoring needs

Along with continuing and implementing new research and monitoring projects, there is a need to conduct analyses of long-term existing data (e.g., water quality, vegetation and fauna surveys). These data analyses should be designed to answer specific questions and should involve collaboration with experts on specific issues. GIS tools could also be used to analyze larger scale habitat changes due to land use as well as to monitor invasive species and evaluate restoration success; similar to what it was done in 2010 to evaluate the extent of wild rice recovery at Jug Bay over a period of two decades.

The study and monitoring of groundwater resources within the Jug Bay area has been somewhat underestimated compared with surface waters. There is a need to learn more about this resource, particularly regarding groundwater contamination, potential for salinization, and the potential compounding impacts of human uses and climate change on groundwater levels.

In addition to current efforts to monitor water quality in estuarine waters, it is important to also monitor water quality and overall habitat health at non-tidal streams. These represent the connecting point between the estuary and uplands and serve as early indicators of water quality and habitat degradation. Some of the creeks in need of new or continue monitoring within the Jug Bay area include Galloway, Pindell, and Black Walnut Creeks.

More studies are also important to assess the short and longterm effects of untreated sewage overflows from the various wastewater treatment plants located around the Jug Bay estuary on water quality, nutrient dynamics, and overall contamination of the aquatic environment.

CHAPTER 4. THE ECOLOGY OF THE MONIE BAY ESTUARY

4.1 OVERVIEW

Monie Bay, a tributary of Tangier Sound, is located in the southeastern portion of Chesapeake Bay just southeast of the Wicomico River mouth, in Somerset County. Within this area and along the northern side of the Deal Island peninsula lies the Monie Bay component (38°13’30”N, 75° 50’00” W), one of three sites that form the Chesapeake Bay National Estuarine Research Reserve in Maryland (CBNERR-MD; Figure 4.1.1). Monie Bay is located approximately 8 miles (13 km) west of Princess Anne, and nearby urban areas include Salisbury (20 miles/32 km), Pocomoke City (21 miles/34 km) and Ocean City (46 miles/74 km). Monie Bay covers approximately 3,426 acres, making it by far the largest of the three components. Monie Bay is in an area that is relatively rural and remote. The land within the boundaries has, for the most part, remained untouched and undeveloped. Perhaps one of its more outstanding features is its relatively pristine natural condition.

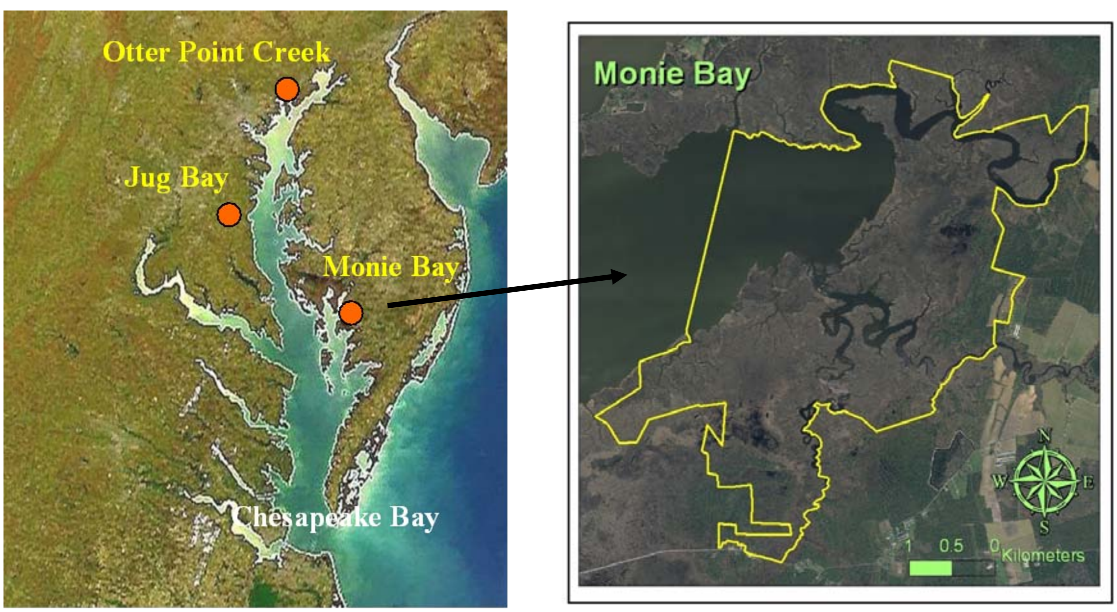


Figure 4.1.1 Geographic location and boundaries of Monie Bay, component of the Chesapeake Bay National Estuarine Research Reserve in Maryland.

Monie Bay constitutes a very large, mostly undisturbed ecological unit which includes habitat for rare and endangered species and provides excellent opportunities for long-term, non-manipulative research. The relatively rural area around the Reserve component has three tidal streams that drain the local area: Monie Creek, Little Monie Creek, and Little Creek (Figure 4.1.2). Monie Bay’s core area is comprised of extensive mesohaline saltwater marshes (extending from the Little Creek watershed to Monie Creek), tidal creeks, pine forests, and shallow open water. The open water of tidal Monie Bay merges with the Wicomico River before reaching Tangier Sound and the Chesapeake Bay.

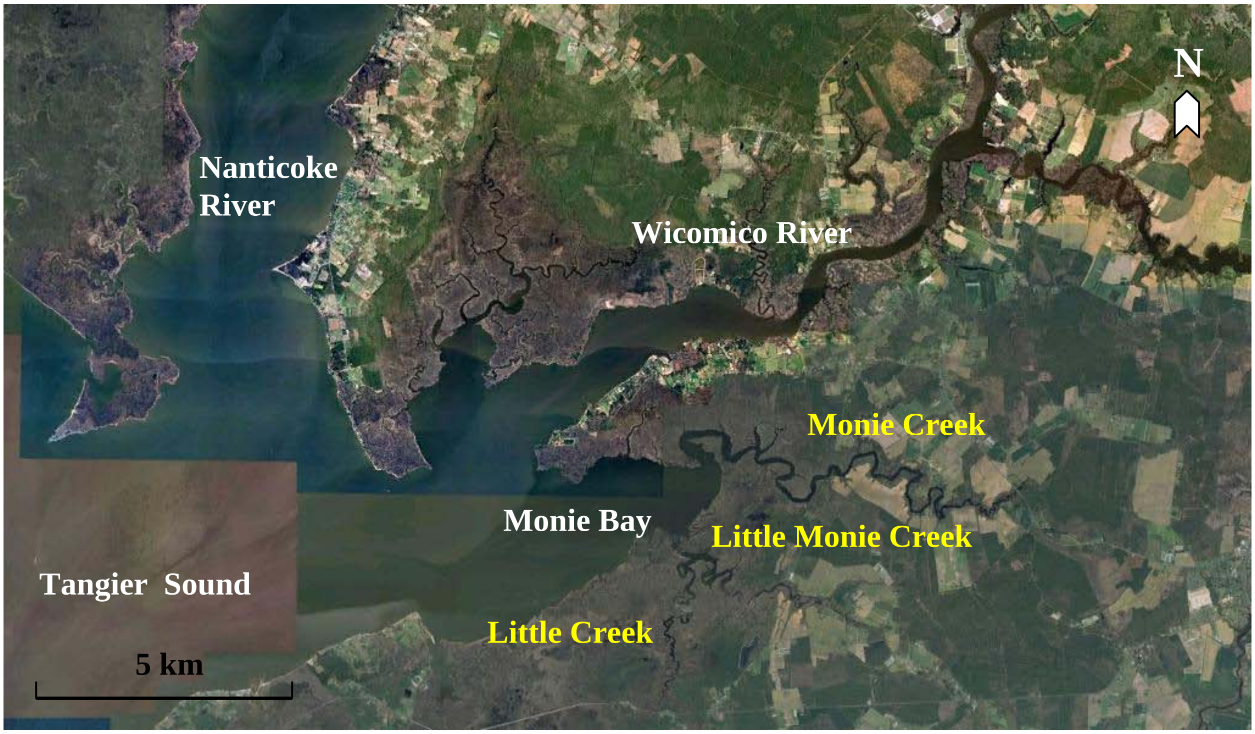


Figure 4.1.2 Location of the three main tidal streams that drain into the Monie Bay component.

Future management of the area should focus on (1) effects of land use, land use change, and best management practices on the tidal creeks; (2) impacts of varying water quality on aquatic species; and (3) how changes in sea level rise may impact the marsh ecosystem and the services it provides.

Although Monie Bay is not as well-studied as the other CBNERR-MD components, several recent research projects associated with this system provide detailed information on Monie's tidal marshes, estuarine waters, and human ecology. Most of the recent Monie Bay research was conducted in support of several CBNERR-MD Graduate Research Fellows, as well as monitoring studies by other researchers from Salisbury University, University of Maryland Center for Environmental Sciences (UMCES) at Horn Point Laboratory, and University of Maryland College Park. In addition, routine and specialized habitat, wildlife monitoring studies have been conducted in this area by various Units of Maryland DNR. Most recently, CBNERR-MD research staff has also started a series of research and monitoring projects in this area that have added to the existing knowledge of this system.

The Deal Island Wildlife Management Area (DIWMA), which includes the area designated as the Monie Bay component of the Reserve, provides public access for recreational uses such as hunting, trapping, fishing, and boating, as well as non-consumptive activities such as bird watching, wildlife photography and hiking. There is no user fee or check-in system for the DIWMA, so visitation estimates are not available. However, visitor use in the Monie Bay component beyond wildlife related recreation (e.g., hunting) is minimal due to its remoteness and lack of easy access. Main access to the Monie Bay component is off Deal Island Road in the community of Monie. However, hurricane Isabel destroyed the entranceway and only marsh and guts remain up to the edge of the main road where there was once a parking area to facilitate access. Therefore, activities are confined to mostly those involving a boat, such as duck hunting and recreational fishing. Current boat access could be attained via Drawbridge Road or from the Dames Quarter public boat ramp located approximately three miles west of the Monie Bay component.

The overall level of visitation is consistent with long term resource protection. Based on current trends in visitation, some increase in the number of non-consumptive uses may be anticipated. A stable number of hunters and fishermen are also anticipated in the foreseeable future. The top priority at Monie Bay has been to acquire property abutting both a road and deep water to provide suitable access for CBNERR-MD education, research, and stewardship programs, and to build appropriate on-site facilities and infrastructure. Recently, in 2011, a 15-ha (37 acres) property (Phillips property), located on the eastern boundary of the Reserve off Drawbridge Road and along Little Monie Creek, was purchased by Maryland DNR and will be soon incorporated as part of the Reserve. This new property provides direct access to the Monie Bay marsh system and includes among other things a house and a small pier that will provide, after necessary refurbishing, some basic infrastructure for the lodging of Reserve staff, research scientists, graduate students as well as easy access to the water and marsh. The acquisition of this new property will greatly facilitate all of our partners and CBNERR-MD's activities in this component.

4.2 HISTORICAL LAND USE AND CULTURAL RESOURCES

The region around the Monie Bay component was first surveyed by the State of Maryland in 1662 along major rivers in the south and west for settlers leaving Virginia, primarily for religious reasons. Proprietary Manors (6000 acres each) were laid out in 1674 for Lord Baltimore's use. The borders of Somerset County were disputed with Virginia and the "Lower Three Counties of Pennsylvania" (now Delaware) between the mid 1600s and 1700s. By 1742 there were 9-10 designated Somerset "Hundreds" (a medieval English term indicating subunits within a county). Among these was the Monie Hundred, which increased in size by more than 3-fold by 1783 (Lyon 2004; Figure 4.2.1).

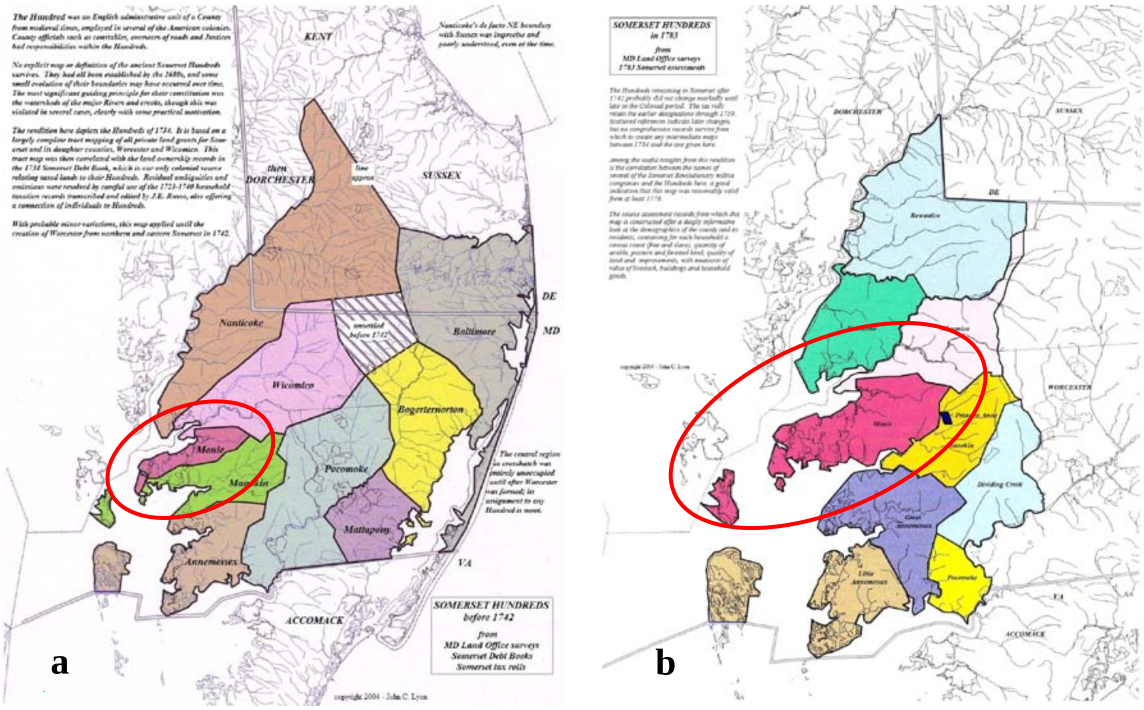


Figure 4.2.1. Monie Bay Hundreds from before 1742 (a) and 1783 (b). Monie is highlighted in pink. Source: Lyon (2004).

Some early settlements around the Monie Bay component were located within the marshes. An old road that used to run from Monie Bay to Princess Anne meandered through the marsh and upland areas connecting houses and communities on its way. Old residents reported that travel to Princess Anne and beyond was easier by water, given the circuitous route of the old road and the often difficult travel conditions if the road was muddy. The fact that people lived within the marshes seemed to indicate a more direct connection between this natural resource and the daily livelihoods of Peninsula residents (Power and Paolisso 2005).

A changing time for the Deal Island Peninsula occurred in the early 1930s when a hurricane washed away community structures such as warehouses, marinas, and general stores that once thrived on the fishing and trading industries. Land and coastal erosion eventually forced people off their lands and settlements were lost to the marsh. The commercial fishing industries, once in abundance, began a gradual decline due to low crab and oyster yields. However, with the paving of Deal Island Road, commerce, some relocation, and political activity accelerated, and growth extended into Salisbury and Princess Anne. Interestingly, social and economic activity typically remained on the Peninsula (Power and Paolisso 2005).

Current common recreational activities around Monie Bay include crabbing, fishing, hunting, wildlife photography, bird-watching, and marsh appreciation and exploration (Power and Paolisso 2005). Most local residents use the marsh in some recreational form and they recognize some of the services marshes provide including critical habitat, buffer between the water and land, and water filtering capabilities of nutrients and other pollutants.

4.2.1 Socio-Economic Setting

Somerset County, where the Monie Bay Reserve component is located, is a very rural and economically depressed region of Maryland. As of the 2009 Census estimates, the county population was 25,959 people, which has changed somewhat from the 1990 Census estimates of 23,440 people. Some of the increased population seems to come from the influx of new residents from Mid-Atlantic urban areas seeking secondary homes in rural areas, particularly along the water (Power and Paolisso 2005). As a result of this, the price of land and real estate has steadily increased and it has become difficult for many local families to pay higher property taxes (Power and Paolisso 2005). About 56 percent of Somerset County residents are white non-Latino, 41 percent are African-American, and 2.7 percent are Latino (US Census Bureau 2010; http://quickfacts.census.gov/qfd/states/24/24039.html).

Crisfield and Princess Anne are the two major business and industrial centers of the County. Somerset is a major seafood processing and poultry producing County. Retail, farming (mainly chicken, soybean, corn, and wheat), and commercial fishing dominate as the main activities in the economic sector (Power and Paolisso 2005); the county also provides a rich harvest of vegetables, including tomatoes. In 1987, the Eastern Correctional Institution was opened in Princess Anne, and employees over 1,000 people (Nancy Ward, pers. comm. 2011).

The per capita personal income based on data collected between January 2006 and December 2008 was $17,360, which is just over half the overall value for the state of Maryland ($34,508; U.S. Census Bureau 2010). Although farming, agriculture, fishing and forestry accounted for 22% of jobs in 1970, this declined to only 17% by 1995. The closing of seafood and produce processing plants during this period caused manufacturing employment to drop from 24% to 7% of all jobs. Meanwhile, service and government jobs increased from 18% to 29% during this same time period (Urban Research and Development Corporation 1998). More recently, government jobs (Federal, State and Local) account for 39.2 % and private jobs for the remaining 60.8 % including retail trade, services, wholesale trade, manufacturing, etc. (Maryland Department of Business and Economic Development 2002).

Somerset County depends on Routes 13 and 413 as its lifelines for all of its socio-economic, political and recreational activities. Route 13 in particular channels thousands of regional vehicle trips a day through the County from New York and Philadelphia to Norfolk and the south (John Pickard Associates, 1991). In addition, traffic increases on Route 13 during the summer months, as some of the over 8 million annual visitors to the ocean follow that route.

4.2.2 Cultural History and Archaeological Resources

Artifacts indicate the presence of Native Americans in the Monie Bay area 13,000 years ago. During the early historical period many different Indian nations occupied the lower eastern shore region. Records indicate that Somerset County was inhabited by the Manoakin and Rockawakinmany Indian nations (Richardson 2011). Overall, the Indian population within the lower eastern shore decreased dramatically during the late 16th through the early 18th centuries as a result of diseases (e.g., small pox) brought by the English and their animals, the wars with the English, and migrations out of the area. However, what finally brought the end of the Indian culture in this region was the possession and settlement of the English in the land as they started to establish a plantation society (Richardson 2011). A more detailed recount about the Indians of the lower eastern shore is found at the Edward H. Nabb Research Center for Delmarva History and Culture website: http://nabbhistory.salisbury.edu/settlers/profiles/shoreindians.html.

The Monie Bay component is known to contain at least six prehistoric archeological sites as a result of an archeological survey conducted in the DIWMA vicinity by the Maryland Historical Trust (Maryland DNR 2008). Colonial settlement began about 1665 with the movement of Quaker groups from the eastern shore of Virginia across the state line to Maryland seeking refuge from Virginia laws which prohibited their religious practices. The Monie "Hundred" or District was settled by both Quakers and members of the Church of England. By 1696, the Monie Bay District is estimated to have had a population of 900.

The plantation economy of Somerset County centered on tobacco in the early 18th century but diversified later in the century. Tobacco plantations were intimately linked to the introduction of the first African slaves, but by the 1750s planters within the eastern shore were using slaves to grow wheat, corn, and vegetables, and to tend livestock. Slave trade in the region slowed down during the 1780s and finally ended during the mid-nineteenth century (Whitman 2011). The first half of the 19th century was prosperous for the County, but the Civil War time period was hard on the agricultural and minor industrial economy. Emigration, agricultural competition, and the breakdown of the slave labor system led to economic failure for many wealthy families. More information and resources about the people and culture of the Delmarva Peninsula can be found at the Edward H. Nabb Research Center for Delmarva History and Culture website: http://nabbhistory.salisbury.edu/settlers/profiles/shoreindians.html.

Crisfield was connected to the railroad system in 1866; during the 1800s and 1890s, the shellfish industry boomed in this town. Shipbuilding was the most significant supportive industry during the 19th and 20th centuries. Princess Anne sustained its economy through the 19th century as a merchant town and county seat. Deal Island was the site of major water-oriented communities full of small businesses and watermen.

4.3 ENVIRONMENTAL SETTING

Monie Bay is a relatively small embayment 1–2 km (0.6–1.2 miles) wide, 4–5 km (2.5–3.1 miles) long from Slaughter Creek to Nail Point with little freshwater input, located near the mouth of the Wicomico River south of the Nanticoke River. Its tidal channels have maximum water depths of approximately 2 m (6.6 feet), with tidal ranges of approximately 0.3 m (1 feet), and salinities generally ranging from 7–17 parts per thousand (ppt) with a spring average of 11 ppt and a winter average of 15 ppt (Ward et al. 1998).

The Monie Bay component comprises three main tidal tributaries varying in watershed size and flushing time, Little Creek, Little Monie Creek, and Monie Creek, which range in salinity from mesohaline to oligohaline. In addition to their range in salinity, they also differ in the amount of development (specifically agriculture) that impacts each creek. Monie Creek is the largest of the three creeks and has a large freshwater input as well as high agricultural input. Little Monie

Creek is slightly smaller with less freshwater input causing salinity to be higher at 10–12 ppt and has moderate agricultural input. Little Creek is the smallest of the three tributaries and has less freshwater inflow and increasing tidal influence with salinity ranging from 12–13 ppt and no agricultural or other development within the watershed. The three different tributaries with their differences in salinity and agricultural input provide a natural experimental design that lends itself to comparison research.

4.3.1 Geologic History

Somerset County, where Monie Bay is located, is in the Atlantic Coastal Plain physiographic province, and is underlain by a wedge of unconsolidated sediments that forms a series of aquifers and confining units (Werkheiser 1990). Monie Bay is situated in a region of low-lying terraces composed primarily of Parsonburg Sands with interbedded clays and shell beds, ranging in age from Miocene to Late Pleistocene (Ward et al. 1998). The region's soils are part of a sequence of alluvial sands and marsh beds to the east, and Holocene Marsh Deposits overlap the lowland Quaternary Deposits on the eastern side of the Delmarva Peninsula containing Monie Bay proper. This western side of the peninsula is broad lowland with surface elevations ranging from 0–10 m (0–33 feet) above sea level that are extensively dissected with bay flats and broad valley bottoms. Monie Bay estuary is bordered by tidal marsh deposits of the Holocene Age, which extend east from the Chesapeake Bay and Tangier Sound across this coastal lowland into the central Delmarva Peninsula. Monie Bay soils are generally classified as tidal marsh soils, containing sands, clay, and sulfurous peaty muck. Most of the upland portions of the site are in the Othello-Portsmith association, comprised of poorly-drained silt loams overlying silty-clay loam subsoils; these soils are strongly acidic (Matthews and Hall 1966).

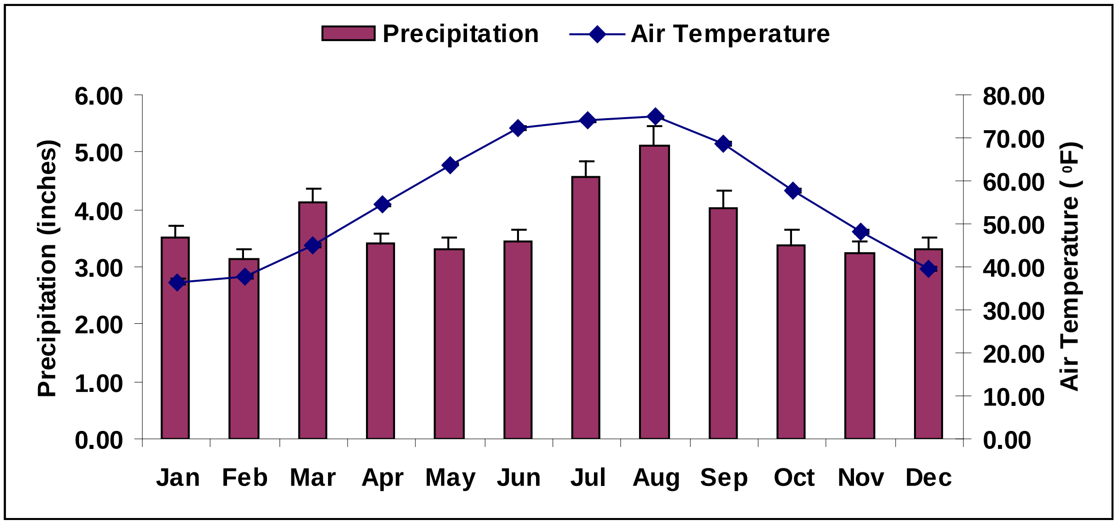
4.3.2 Climate and Weather

The climatic conditions at Monie Bay are humid and semi-continental, with mild winters and hot summers. Prevailing winds are from the west such that the Atlantic Ocean influences weather patterns only occasionally, as with periodic northeaster storms. The average growing season length is approximately 230 days within the Monie Bay watershed. Weather information presented in the following sections is based on data collected from the Princess Anne weather station located in Somerset County (38°13'N / 75°41'W). This station has been operating since 1948 and it is still active; all weather data was downloaded from the National Climatic Data Center, NOAA Satellite and Information Service (http://www4.ncdc.noaa.gov).

4.3.2.1 Weather annual patterns

The average annual rainfall within the Monie Bay area is approximately 1092 mm (43 inches); with July and August among the wettest months of the year. Overall, precipitation seems to be fairly evenly distributed throughout the year, with a monthly average precipitation ranging between 79 and 130 mm (3.12 and 5.11 inches, Figure 4.3.1).

The average annual air temperature is approximately 13°C (56 °F) with average monthly maximum temperatures in July and August of about 23 °C (74-75 °F) and average minimums in January and February of 2-3 °C (37-38 °F, Figure 4.3.1).



	J	F	M	A	M	J	J	A	S	O	N	D
Temp.	36.58	37.81	45.11	54.43	63.75	72.23	74.00	74.89	68.61	57.78	48.23	39.60
Precip.	3.52	3.12	4.14	3.40	3.32	3.45	4.56	5.11	4.01	3.39	3.23	3.30

Figure 4.3.1 Monthly average air temperature and precipitation; Princess Anne weather station in Somerset County, Maryland. Data range: 1931-2010. Data source: National Climatic Data Center, NOAA Satellite and Information Service.

4.3.2.2 Storm events

Storm event information for Somerset County from January 01, 1950 to August 31, 2010 was obtained from the National Climatic Data Center, NOAA Satellite and Information Service (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwevent~storms). Storm events are classified in different types as indicated in Table 4.3.1. Most weather events listed in Table 4.3.1 correspond to the period between 1993 – present; except for tornados, and thunderstorm winds and hail which date from 1950 and 1955, respectively. Considering all the different types of storm events, a total of 129 events have been recorded for Somerset County; from these, coastal floods, high winds, hurricanes, ice storms, lighting, thunderstorm wind, tornados, and tropical storm have been the cause of a total county property and crop damage during this time period of approximately $14.5 and $6.6 million dollars, respectively. The tornados of 1981 and 2002 reached velocities in the range of 73-112 mph (63-97 knots) following the Fujita tornado scale.

Table 4.3.1 List of storm events that have occurred in Somerset County between 1950 to present. Those events highlighted were responsible for property and crop damage for the county. Data source: National Climatic Data Center.

Event Type	Date (s)	Number of Events
Blizzard	2/9/2010	1
Coastal flood	5/12/2008, 11/12/2009	2
Droughts	9/1/1995, 11/1/1998	2
Excessive heat	5/18/1996	1
Extreme cold	2/5/1996	1
Flash flood	7/5/2006	1
Frost/freeze	10/24/2003	1
Hail		18
Heavy rain		6
Heavy snow	12/28/1993	1
High wind	9/1/2006, 5/11/2008, 9/22/1994	3
Hurricane	7/13/1996, 9/6/1996, 9/15/1999	3
Ice storm	12/23/1998	1
Lighting	8/12/2010	1
Snow	1/9/1997	1
Thunderstorm wind		43
Tornado	9/8/1981, 1/6/2002, 5/13/2002, 7/14/2003, 7/5/2006	5
Tropical storm	10/8/1996, 9/18/2003, 9/6/2008	3
Winter storm		21
Winter weather		6
Winter weather/mix		8

Note: Dates were not posted for events occurring more than five times.

4.3.3 Estuarine Geomorphology, Soils, and Sedimentary Processes

4.3.3.1 Accretionary patterns

Accretionary patterns for the Monie Bay area, a mesohaline tidal embayment located near the mouth of the Wicomico River and at approximately 10 km (6 miles) south from the Nanticoke River, were analyzed as part of a study conducted by Ward et al. (1998). A summary of relevant findings from this study regarding soil characteristics, stratigraphy, and marsh accretion are presented below.

Monie Bay marshes, as most marshes within the Chesapeake Bay, do not show the common formation of levees along main tidal channels of other marshes around the country. This process is limited by the microtidal nature of this environment, characterized by reduced flooding frequency and intensity, which limits sediment deposition on the edge of the marsh and inland. The delivery of sediments, particularly in the interior marsh, is further influenced by the variability in marsh microtopography, marsh type and density, the presence of nearby channels, and the occurrence of storm events. These same factors seem to be important in determining the grain size distribution of sediments in marshes such as Monie Bay. Coastal marshes overall show landward fining sediment patterns as a result of deposition of larger particles closer to the tidal channels. In Monie Bay, however, not all areas sampled by Ward et al. (1998) presented this trend. Storms, particularly if accompanied by storm surges, can carry coarser materials further into the marshes changing this simple landward fining pattern.

Relationships among textural properties and the underlying strata of marsh soil cores show four main stratigraphic sequences within the Monie Bay area: (1) emerging (found in channel margin and interior marsh subenvironments), (2) submerging or mineral matter enriched (also found in either channel margin or interior marsh sites), (3) bay margin, (4) and submerged upland. These sequences reflect physical and biological processes, depositional changes over time, and anthropogenic effects within the watersheds.

In general, the marsh development in Monie Bay has been the result of a continuous sedimentary process initiated by deposition over subtidal estuarine flats, channel deposits, or coarser grained pre-Holocene sediments. Continue sedimentation lead to a change from subtidal deposits to intertidal flats, which continue to expand until they became colonized by vegetation, finally resulting in well developed marshes.

As sediments are deposited, the inorganic material shows an upward sequence from coarser toward finer sediments (Howie, 1987 cited by Ward et al. 1998). The organic matter increases towards the surface particularly as the marsh evolves and the availability of organic material increases from detritus, root growth, rhizomes, and plant litter. An increase of organic matter in the upper sediment layers is tied with a decrease in soil bulk density, reflecting the negative relationship between these two soil parameters (Kearney et al., 1994). Conversely, the subsurface sediments become denser due to compaction from dewatering and the loss of organics from decomposition (Ward et al. 1998).

In Monie Bay, cores taken from channel margins and interior marsh showed a stratigraphic sequence similar to the emerging marsh, where grain size decreases upward while organic matter content increases (organic matter is represented by Loss on ignition-LOI). Often, however, most cores showed a change from this sequence reflected by a sharp or gradual decrease of organic matter content near the surface. This corresponds to a submerging or mineral matter enriched marsh sequence and it was the most common sequence found in the Monie Bay channel margin and interior marshes (Figure 4.3.2).

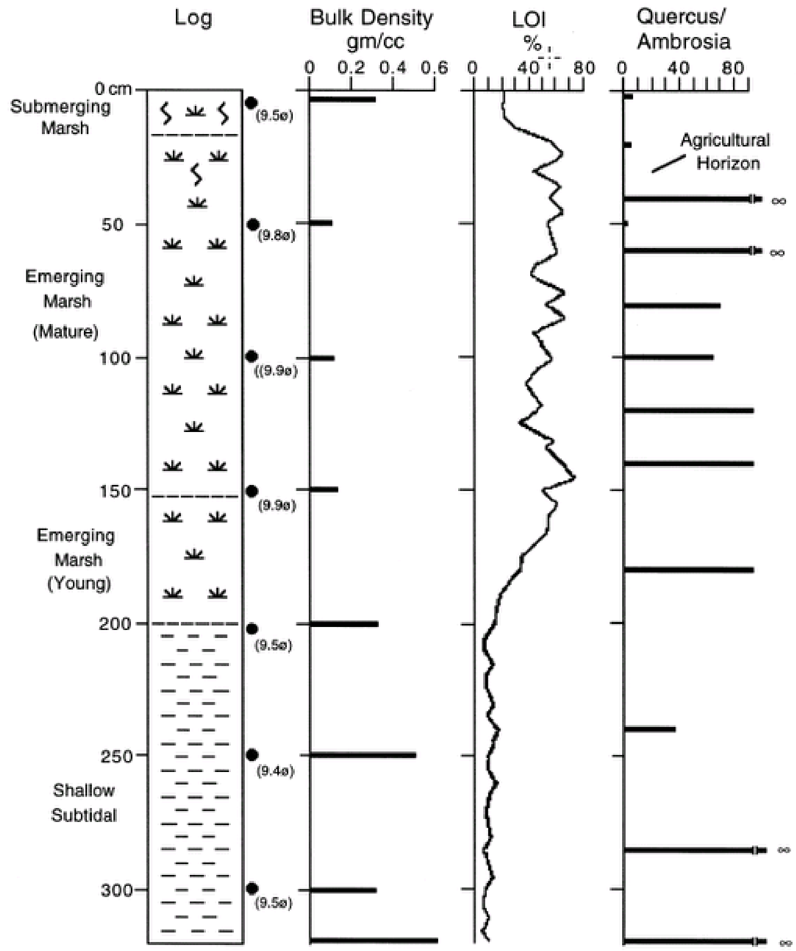


Figure 4.3.2 Stratigraphic characteristics of a core taken from a channel margin subenvironment in Monie Bay. This sequence is typical of channel margins or interior marshes that are submerging or have an increase in mineral matter deposition with respect to organic matter deposition (submerging or mineral matter enriched marshes). The agricultural horizon shown was determined from *Quercus*/*Ambrosia* pollen ratios and corresponds to a period of time when extensive land clearing occurred (approximately 200 years BP) due to farming activities by European settlers (Kearney and Ward 1986). Source: Ward et al (1998).

Monie Bay marshes found along the marsh-forest boundary correspond to the submerged upland stratigraphic sequence. This sequence is similar to the emerging marsh with a fining upward trend and organic matter increasing towards the sediment surface; with the difference that the sediment layer is thin (less than 2 m or 6.6 feet) and composed of highly organic mud (40-70 %). The soil deposits below the submerged upland marshes are often formed by poorly sorted-very fine sands to silt. This characteristic and pollen profiles seem to indicate that these marshes are young and formed after the colonial agricultural land clearance that occurred approximately 200 years ago (Kearney and Ward 1986).

Areas within the Monie Bay open embayment correspond to a different kind of marsh stratigraphic sequence: the bay margin. In this environment storm overwash or strong wave conditions dominate the depositional processes. As a result, the upper layer of the sediment column is characterized by sandy overwash deposits mixed with fine-grained marsh sediments which results in a coarsening sequence upward. This sequence also shows a decrease in organic matter content near the surface. Overwash deposits are colonized by vegetation particularly *Spartina alterniflora* (smooth cordgrass) and then incorporated into the marsh stratigraphic sequence.

At a regional or large-scale perspective, Monie Bay shows evidence of meandering and aerial photograph analyses have shown channel bank erosion (Ward et al. 1988); which Ward et al. (1998) suggest might be an indication of early stages of submergence of the marshes due to sea level rise.

4.3.3.2 Vertical accretion

The rates of vertical accretion during the last two centuries have been studied within the Monie Bay marsh system by using three different geochronological methods: pollen analysis, and radionuclide dating using ^{137}Cs and ^{210}Pb. Pollen analysis is used to determine long-term accretion rates (approximately 200 yrs) and it is based on the detection of a decline in the pollen of oak (*Quercus* spp.) and a sharp rise in the pollen of agricultural weeds like ragweed (*Ambrosia* sp.) that have resulted from the large-scale European land clearance that occurred around the Chesapeake Bay from the middle of the 17th century through early 19th century. Radionuclide dating with ^{137}Cs and ^{210}Pb is used to determine accretion rates on the ranges of 30 and 100 yrs, respectively (Kearney et al. 1994, Ward et al. 1998).

Results of pollen analysis conducted by Ward et al. (1998, 1988) showed accretion rates at Monie Bay marshes ranging between 1.5 to 6.3 mm yr^{-1} (0.06 to 0.25 in. yr^{-1}, Figure 4.3.3). Many of the sites measured by Ward et al. (1998) had values lower than the local rate of sea level rise for the Chesapeake Bay which ranges from 2.7 to 4.5 mm yr^{-1} (0.11 to 0.18 in. yr^{-1}, Larsen 1998). This may indicate that Monie Bay marshes might not be able to keep pace with projected sea level rise estimates.

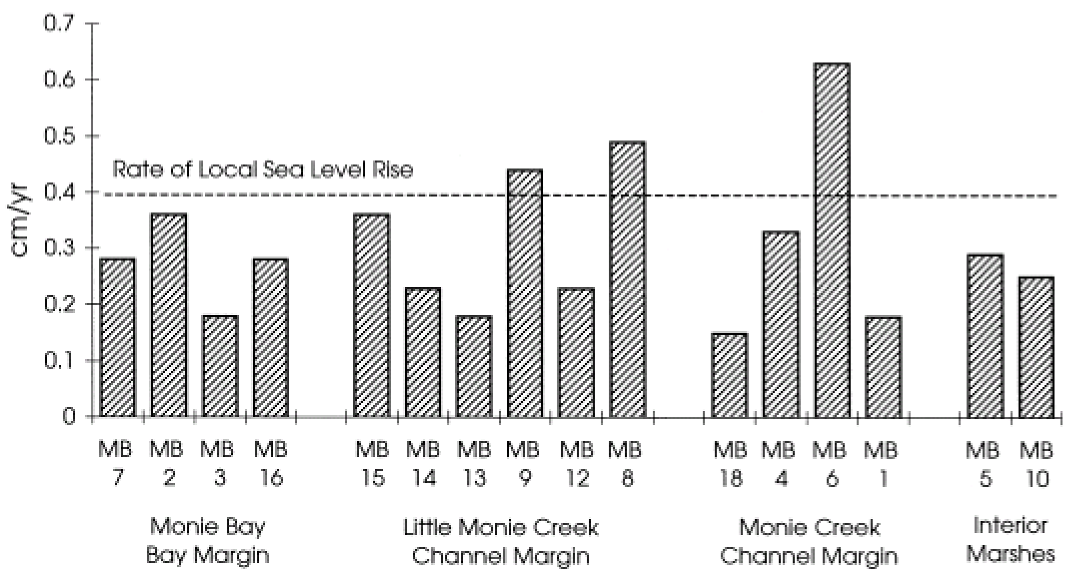


Figure 4.3.3 Accretion rates for the estuarine embayment marsh located at Monie Bay. MB1-MB18 correspond to different sampling sites. Source: Ward et al. (1998).

Ward et al. (1998) also showed that Monie Bay marshes do not tend to always follow two general trends often found in wetlands. (1) Monie Bay marshes do not always show an increase in accretion from downstream to upstream; this is probably due to the fact that the channels found in Monie Bay marshes are entirely tidally driven, with no connection to up-estuary rivers or streams limiting the amount of mineral sediments entering the system. (2) Monie Bay marshes do not always show a decrease in accretion from the margin of water channels towards the interior of the marsh. Changes in marsh topography, which alters flooding duration, and storm events might be causing more complex sedimentation patterns in Monie Bay marshes.

A comparison of vertical accretion rates obtained by using ^{137}Cs and ^{210}Pb radionuclide dating and pollen dating showed significant differences among methodologies, indicating that a single marsh site might be characterized by different rates depending on the time interval being considered (Kearney et al. 1994). For example, accretion rates estimated using ^{137}Cs (time interval of approximately 30 yrs) was twice as high as the rates calculated using ^{210}Pb and pollen analysis, which estimate rates on the order of 100 and 200 yrs, respectively (Figure 4.3.4; Kearney et al. 1994). Lower rates for the longer time intervals may be explained as older sediments go through decomposition, compaction, and other subsurface processes. The temporal as well as spatial variability found while estimating marsh accretion rates complicates things as scientists try to determine a marsh's ability to keep pace with sea-level rise.

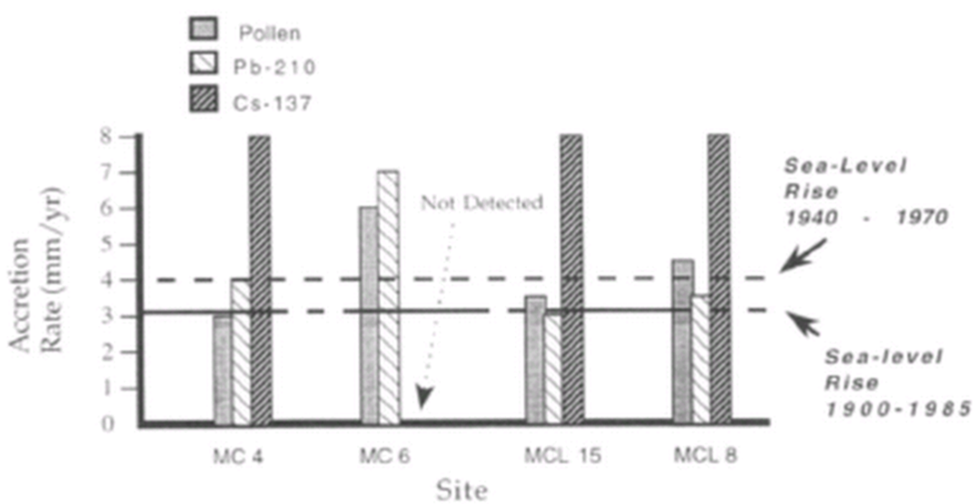


Figure 4.3.4 Comparison of vertical accretion rates at four Monie Bay marsh sites determined by three different geochronology techniques to average rates of sea-level rise based on the Baltimore (1900-1985) and Solomons (1940-1970) tide gauge records. The time interval for ^{137}Cs is approximately 1963 to 1987; ^{210}Pb 1887-1987; and pollen 1790-1987. Source: Kearney et al. (1994).

Based on Figure 4.3.4, we may say that Monie Bay marshes are easily keeping pace with the rate of sea level rise based on ^{137}Cs vertical accretion rates; on the other hand, the same marshes may just be at the threshold of maintaining elevation if looking only to the long-term ^{210}Pb and pollen rates. These results seem to highlight a potential overestimation of marsh accretion rates when calculated using methodologies that encompass shorter time intervals such as ^{210}Pb dating and marker horizons (Kearney et al. 1994).

Although integrated long-term vertical accretion rates for the Monie Bay system averaged about 3.0 mm yr^{-1} during the last two centuries, there is considerable spatial variability in these rates (as indicated above), highlighting the importance of the delicate balance between sediment accretion rates and sea level rise and Monie Bay marshes' susceptibility to substantial loss through erosion (Stevenson et al. 1988) and increased flooding. Natural compaction processes and disturbance by storms could exacerbate marsh loss, with interior ponding often appearing as an intermediate phase in marsh deterioration (Kearney et al. 1988). Although Monie Bay marshes appear to be relatively stable over the last several decades (Ward et al. 1988), inputs of terrestrial sediments to these marshes are relatively limited compared to riverine marshes along the Nanticoke River, making Monie Bay marshes more susceptible to long-term degradation (Ward et al. 1998).

4.3.3.3 Sediment characteristics

Through a study conducted by Kearney et al. (1994), the marsh sediments of Monie Bay were characterized along three main marsh environments: shoreline, tidal channels, and marsh interior (Table 4.3.2). Shoreline marshes had the largest percentage of sand and mean grain size reflecting sand input from overwash during major storms. The interior marsh was characterized by somewhat smaller grain size; the result of probably less flooding and storm impact reaching this zone.

Because of the larger amount of sands in shoreline sites, these also were characterized by higher values of dry bulk density, ranging from 0.30 to 1.23 grams per cm^3. More organic soils had lower dry bulk density values. Overall, bulk densities increased with depth (Kearney et al. 1994).

Table 4.3.2. Characterization of surface sediments at shoreline, channel side, and interior marsh environments in Monie Bay. Values in parenthesis indicate standard deviation. Source: Kearney et al. (1994).

Marsh Environment	Sand/Silt/Clay	Mean Grain Size (μ)	Mean % Organic	Mean % Water	Average Dry Bulk Density (g cm^{-3})
Shoreline	76/22/1	140.40 (212)	9.0	22.3 (32.0)	1.23
Channel side	1/34/65	1.40 (0.25)	25.4 (8.9)	65.7 (5.8)	0.36 (0.13)
Interior	1/31/69	1.42 (0.42)	34.2 (12.9)	74.4 (7.2)	0.30 (0.19)

The content of organic matter on Monie Bay marsh soils varied significantly with depth (1 – 69%) with those marshes exposed to higher energy by the shoreline showing a decrease in organic content. This decrease, particularly in the upper level of the soil profile, often reflects storm deposition of sands, such as that which occurred during tropical storm Agnes in 1972. In contrast, the sediments of the interior marsh are characterized by higher organic content, although the organic content decreases sharply below the top 30-40 cm of the soil surface (Kearney et al. 1994).

4.3.4 Hydrology

Monie Bay is a small (1 - 2 km or 0.6 – 1.2 miles wide, 4 km or 2.5 miles long), shallow (1.9 ± 0.1 m or 6.2 ± 0.3 feet), tidally influenced embayment that receives freshwater inputs from three creeks: Monie Creek, Little Monie Creek, and Little Creek, varying in watershed size and flushing time. Flushing time for Monie Creek, Little Monie Creek, and Little Creek is 1.2, 1.9, and 12.4 days respectively (Fertig et al., unpublished data). Tidal flushing from Monie Bay, springtime flows, and intermittent precipitation act to control salinities in Little Monie Creek and Little Creek, while a stream provides freshwater to Monie Creek year-round (Jones et al. 1997). Tidal scouring, rather than fluvial input, formed these creeks (Ward et al. 1998), but freshwater nutrient delivery, associated with land use, over spatial and seasonal patterns is a key driver of their overall variability (Apple et al. 2004).

4.3.4.1 Tides

Tides in Monie Bay are semi-diurnal and have a mean range of 0.3 meters (one foot). The average water levels are generally lower in the winter due to north and northwest winds that increase water egress from the Chesapeake Bay. On the other hand, water levels tend to be higher in the spring and summer when southerly winds reverse the process. As indicated above and similarly to other shallow estuarine system, the role of wind speed and direction on the marsh water level is very important.

4.3.4.2. Aquifers and groundwater

There are seven major aquifers underlying the Somerset/Monie Bay region: 1) the first of these is the Surficial aquifer, which is relatively thin throughout the county. The Surficial aquifer has limited capacity and its water is generally soft to moderately hard and slightly acidic with high nitrate concentrations in areas near farming and elevated iron concentrations in areas containing anoxic water. 2) The Pocomoke aquifer, which is present only in the southeast part of the county, has elevated concentrations of iron and manganese. 3) The Manokin aquifer is the principal source of drinking water for human use in Somerset County. It has highly variable water quality ranging from relatively soft water low in solutes to the south and east to hard water high in chlorides towards the Chesapeake Bay. Water in the Deal Island/Monie Bay component area has chloride concentrations exceeding US Environmental Protection Agency (USEPA) standards. The 4) Paleocene and 5) Potomac aquifers supply water to major towns and cities in Somerset and other counties along the Bay. The last two aquifers are 6) the Choptank and 7) Piney Point; the Choptank contains high chloride concentrations and the Piney Pont contains high concentrations of dissolved solids. Model analyses suggested that projected increases in human water use in the region could encounter salinity problems within 50 years (Hamilton et al. 1993, Werkheiser 1990).

The chemical character of natural water in the Surficial Aquifer is controlled primarily by the chemical properties of precipitation, in combination with mineral dissolution and biological activity in the aquifer (Hamilton et al. 1993). Like precipitation, natural ground water is moderately acidic (pH approximately 5.8), and concentrations of dissolved constituents are low because the Surficial Aquifer consists mostly of relatively insoluble quartz sand. The high permeability of soils increases ground-water-flow rates and reduces contact and reaction time between water and aquifer minerals. Nitrate, derived from nitrification of ammonia in inorganic fertilizers and manure, is the dominant anion in agricultural areas, with concentrations ranging from 0.4 to 48 mg N l^{-1} (median = 8.2 mg N l^{-1}). Nitrate concentrations exceeded the USEPA maximum for drinking water (10 mg N l^{-1}) in approximately 33% of the 185 water samples, although this was not the case for a sample taken from a well within the Monie Creek watershed, which had a nitrate concentration less than 0.10 mg N l^{-1} (Table 4.3.3).

Effects of agricultural activities on ground water quality are not limited to the near-surface parts of the aquifer underlying farm fields, but are common at or near the base of the aquifer, 25–35 m land surface. Elevated concentrations of nitrates in deep ground water reflect recharge through distant agricultural or residential land rather than through agricultural or residential land directly around a well (Shedlock et al. 1999). Nitrate concentrations are minimal or less than the laboratory reporting limit in ground water beneath agricultural or residential areas underlain by fine sand, clay, silt, peat, and other organic matter (Hamilton et al. 1993). Recent studies suggest that forest buffers could help reduce nitrate input to ground waters in the region; other factors that may affect nitrate concentration in groundwater include soil texture, organic matter content, and groundwater flow paths (Speiran et al. 1997).

Currently, the communities surrounding the marshes do not have public sewerage. Informants reported that some years back there was a referendum on whether to have public sewerage, versus septic tanks. The referendum was voted down. Part of the stated reason for a majority lack of support for a public sewerage system was the belief that the system would have to be situated in the marshes, which raised at least two concerns for residents: the ecological impact on the marsh, and the belief that it would hasten development (Brown and Paolisso 1995).

Table 4.3.3 General description of aquifer composition at selected wells in the central part of the Delmarva Peninsula; grouped by well network and presented in order of increasing nitrate concentration. Well number 457 corresponds to the Monie Creek watershed. Source: Hamilton et al. (1993).

Well - Map Number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)	Well Depth (feet below land surface)	Nitrogen, nitrite plus nitrate, dissolved (mg l^{-1} as N)	Description of Aquifer Composition
Existing Well Network					
239	38 30 03	75 50 48	15	< 0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam sand
242	38 32 06	75 47 03	70	< 0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam sand
457	38 11 54	75 42 29	60	< 0.10	Clay, silt, and fine sand of the Kent Island Formation (30 ft) overlying the Beaverdam sand
469	38 12 01	75 39 19	27	< 0.10	Parsonsburg sand (2ft) and clayey part of Omar formation (10ft) overlying the Beaverdam sand
478	38 09 40	75 45 45	65	< 0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam sand
492	38 07 01	75 39 47	35	< 0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam sand
500	38 00 05	75 51 07	55	< 0.10	Clay, silt, and fine sand of the Kent Island Formation overlying the Beaverdam sand
604	38 27 48	75 44 12	60	< 0.10	Parsonsburg sand (15ft) overlying the Beaverdam sand

Note: Remaining samples from a total of 185 are not presented here.

4.3.5 Land and Water Use History

4.3.5.1 Land use and land use changes in Somerset County

Land use in Somerset County is largely rural, with areas of intensive poultry feeding operations in addition to large tracts of corn and soy beans, pine plantations, and extensive wetland and forest areas. About one third of the county is farmland, which occurs generally along rivers and creeks. Most of the wetland areas are found along the Pocomoke and Tangier Sounds, east of Deal Island and along the Manokin and Big Annemessex rivers. Large wetlands are also found south of Crisfield and most of the islands in the county are wetlands. Forests, on the other hand, are scattered throughout the county, with the largest areas found north, east, and west of Princess Anne, around Oriole, Shelltown, along the Dividing Creek, within Dublin swamp, east of Westover, and south of Marion (Board of County Commissioners of Somerset County 1988).

Between 1972 and 1981 some important changes that occurred in Somerset County included the conversion of some areas of farmland to cropland, and the development of some cropland areas near Mt. Vernon, Chance, Marion, Pokomoke, and Crisfield. Some wetlands were filled or drained and converted for agriculture or forests. During the period of 1981–1985 not many changes occurred, but some included the presence of timbered areas as brush while waiting for reforestation. This, however, only affected about 5% of the total County's land area. Other minor changes included some conversion of forests to cropland and forest and cropland to development (Board of County Commissioners of Somerset County 1988).

During the late 1990s, land use in Somerset County was comprised of approximately 30% farmland, 42% forests, and 28% undeveloped wetlands (Figure 4.3.5). Nearly 15% of the County's land area is part of state or federal recreation and wildlife management areas, primarily along the waterfront (Urban Research and Development Corporation 1998).

4.3.5.2 Land use characterization of Monie Bay watersheds

Watersheds for the three primary tidal creeks that drain and define the Monie Bay NERR site have different mixes of land-use types (Figure 4.3.6). Little Creek watershed has 35% forested land, 63% marshland, 1% farmland, and 1% residential, while Little Monie Creek and Monie Creek have similar land-use distributions with, respectively, 52% and 58% forested land, 20% and 16% marshland, 25% and 23% farmland, and 3% residential land (Apple et al. 2004). Oblique angle aerial photographs illustrate the dominance of marshlands surrounding Monie Creek near its mouth, while forest and farming land-uses dominate the upper reaches of this Creek's watershed.

Local land uses along each of Monie Bay's creeks have previously been linked to the aquatic ecology of the ecosystem, driving intra- and inter-creek environmental gradients in salinity, nutrients, and dissolved organic matter quality and quantity (Apple et al. 2004).

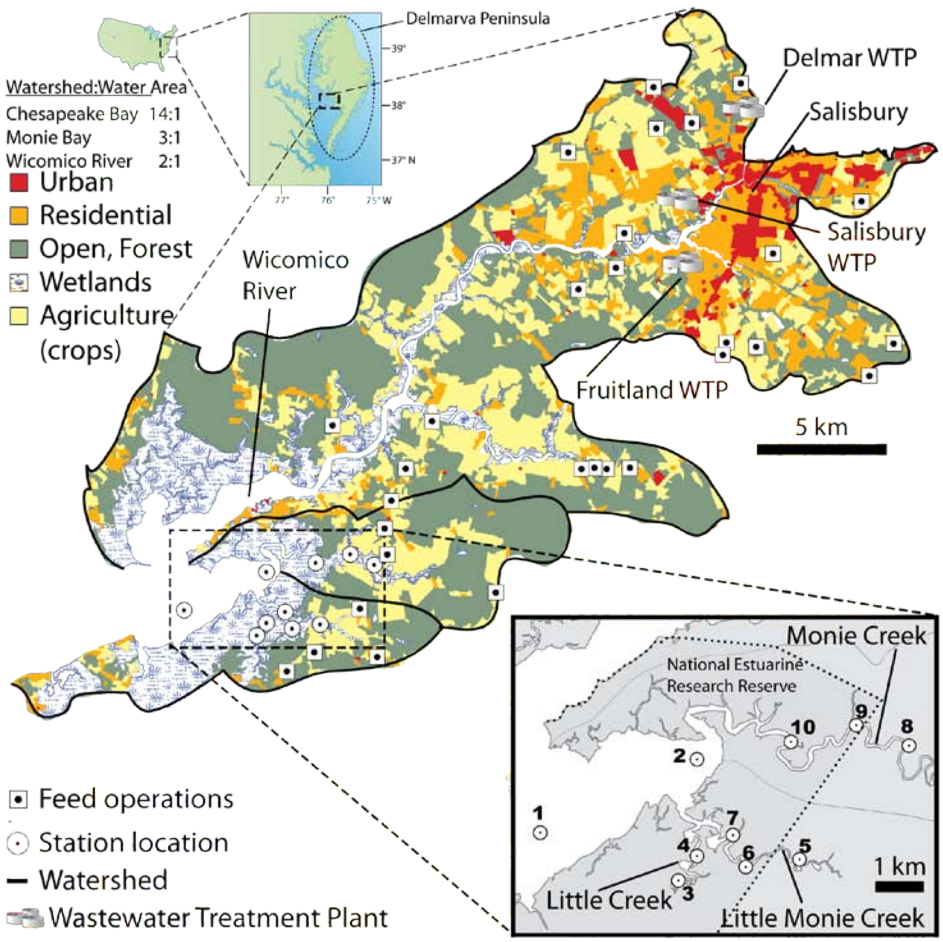


Figure 4.3.5 Location of Monie Bay within the Delmarva Peninsula, and land use within the Monie Bay sub-watershed and the Wicomico River watershed. CBNERR-MD discrete water quality sampling stations (1-10) within Monie Bay's tributary creeks are listed. Source: Fertig et al. unpublished data.

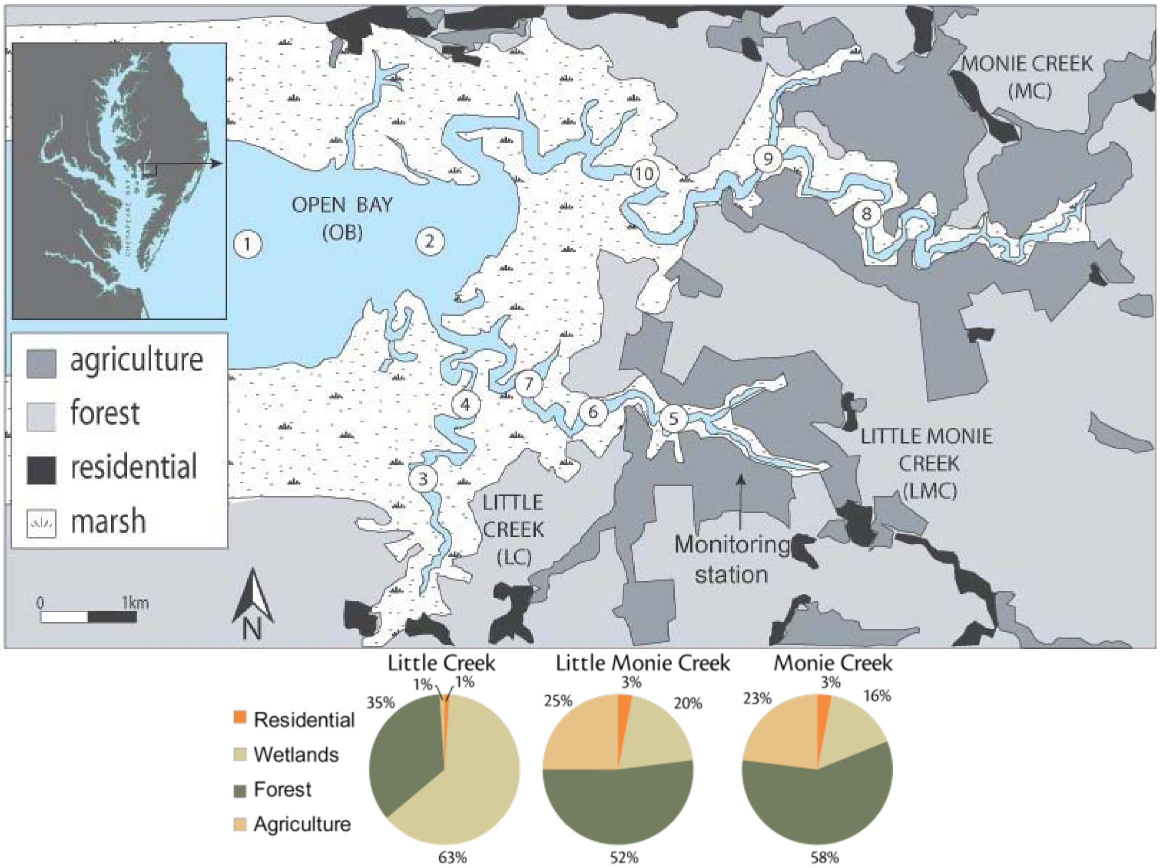


Figure 4.3.6 Land use within the Monie Bay sub-watersheds of Monie Creek, Little Monie Creek, and Little Creek. CBNERR-MD discrete water quality sampling stations (1-10) within Monie Bay are also noted.

Most forests in the watersheds of Monie Bay's tributaries are largely managed as unfertilized tree farms mainly because of economic constraints (Fykes personal communication). Tree farms, mainly *Pinus taeda* (loblolly pine), are also abundant in this county (approximately 60,000 acres are owned by the state but managed privately), and as other forested areas are generally not fertilized due to economic constraints (Fykes, personal communication). Tree farm plots are initially grown out 'naturally' (growth or species selection are not controlled) for 15 - 20 years. Plots are then 'thinned', where brush, junk, and young pines are selectively felled for use as pulp. At this time selective herbicides are used to remove everything but rows of *P. taeda*. Anecdotal evidence suggests that some wildlife populations, including deer and turkeys, increase at this stage. The rows of loblolly pine are grown for an additional 20 years before clear-cut harvesting for lumber and starting at the beginning of the cycle again.

Poultry production is also located in the watershed, and 19 poultry houses have been counted from tiled digital ortho-imagery (1 m ground sample distance) collected during the agricultural growing season (USDA 2005). While no wastewater treatment plants are located in the watershed of Monie Bay, the watershed of the adjacent Wicomico River contains three. Their nitrogen loads for 2002 were: Salisbury approximately 1.8×10^5 kg N yr^{-1}, Fruitland approximately 9.1 × 10^3 kg N yr^{-1}, and Delmar approximately 5.9 × 10^3 kg N yr^{-1}). These three wastewater treatment plants discharge their effluents into the Wicomico River, which meets Monie Bay at its mouth (Figure 4.3.5).

4.3.5.3 Wetland coverage and change

Both state and federal governments are significant landowners within Monie Bay's watershed and Somerset County generally; nearly 15% of the land is designated as recreation or wildlife management areas. One such area is the CBNERR-MD Monie Bay component.

Wetlands are a prominent and important feature of Somerset County. According to Tiner and Burke (1995) in 1981/1982 wetlands in the County equaled 81,563 acres, which corresponds to 13.6% of the State's total. Somerset has the second highest wetland acreage for the State, being topped only by Dorchester County with a total of 169,168 acres. Figure 4.3.7 shows the percentage of each Maryland County's land surface occupied by wetlands; wetlands in Somerset covered approximately 37.7 % of its land surface.

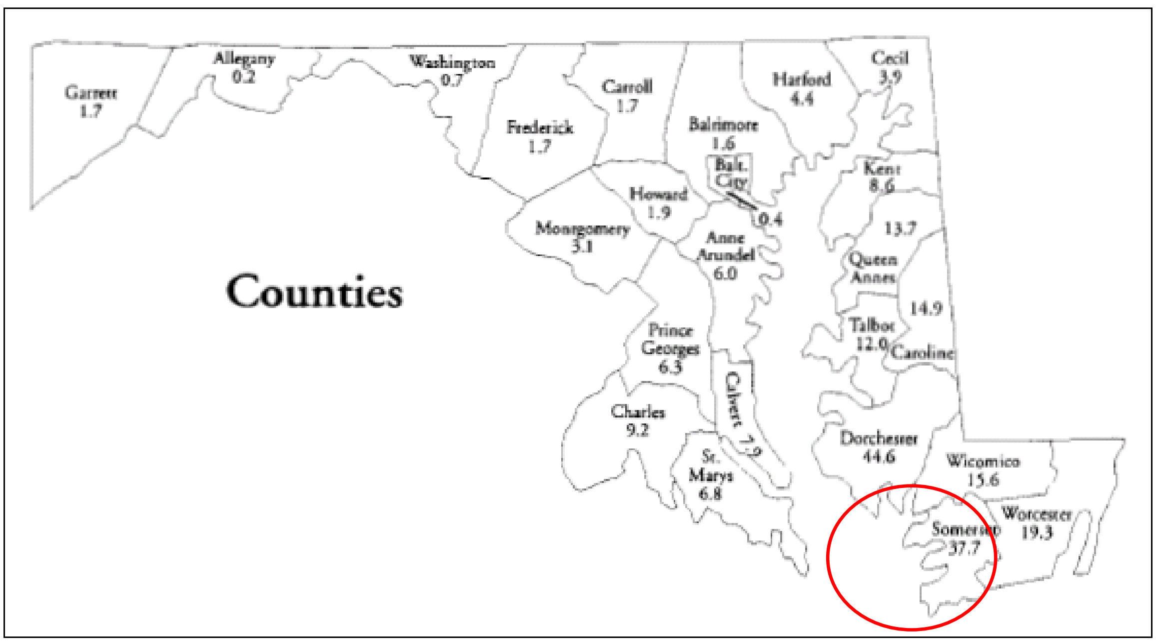


Figure 4.3.7 Percentage of land surface occupied by wetlands given by each of Maryland's Counties. Source: Tiner and Burke (1995).

Through history, the way humans have perceived wetlands has changed and with that how they have used and managed them. One of the earliest inventories of Maryland's wetlands was conducted during the early 1900's (1908-1909) with the main purpose of identifying wetlands to be drained or converted to agricultural and other uses. After this, other major efforts to map the wetlands of Maryland (cited by LaBranche et al. 2003) were conducted in 1954 by the U.S. Fish and Wildlife Service (Report: Wetlands of Maryland), in 1965 (Report: Classification and

Inventory of Wildlife Habitats in Maryland) and then in 1967-1968 by the Maryland State Planning Department (Report: Wetlands in Maryland, 1972), in 1976-1977 by Maryland DNR (McCormick and Somes 1982), and others have followed after these. Comparisons among surveys to estimate historical wetland loss/gain have been complicated by the fact that different surveys used different wetland classification systems and somewhat different methodologies.

In an attempt to quantify wetland losses/gains among all the Maryland counties, LaBranche et al. (2003) conducted a change analyses by comparing historical wetland acreage to that estimated by Tiner and Burke between 1981–1982 (1985). Historical wetland acreage was calculated using acreage of "potential" hydric soils in Maryland by county based on Soil Conservation Service maps (this method is believed to generate an over-estimation), while wetland acreage calculated by Tiner and Burke (1985) was based on photointerpretation and field work. Results of this analysis showed approximately 51%, or 85,893 acre, wetland loss for Somerset County (Table 4.3.4). A gain of 1,326 acres was estimated for the period 1998-2001 (LaBranche et al. 2003).

Table 4.3.4 Wetland acreage change estimates for each of the Counties that host a CBNERR-MD component. Otter Point Creek (Harford County), Jug Bay (Anne Arundel and Prince George's County), and Somerset (Monie Bay). Source: LaBranche et al. (2003).

County	Historical Acreage	1981-1982 Acreage	Loss (Acres)	Percent Loss	Wetland Gains 1998-2001 Acreage
Harford	38,805	16,156	22,649	58	39
Anne Arundel	18,300	12,527	5,773	32	105
Prince George's	41,647	19,516	22,131	53	207
Somerset	167,456	81,563	85,893	51	1,326

In 1994 Tiner and Foulis prepared a U.S. Fish and Wildlife Service report entitled "Wetland trends for selected areas of the lower eastern shore of the Delmarva Peninsula: 1982 to 1988-90", that estimated some wetland changes for part of Somerset and surrounding Counties. According to this report, over 187 acres of mainly palustrine forested wetlands were converted to uplands (agriculture and ditching), and over 2,700 acres were converted to other types of wetlands, most likely as a result of the establishment of loblolly pine plantations and the harvesting of forested wetlands. The new established wetlands consisted mainly of scrub-shrub or emergent wetlands (Tiner and Foulis 1994, cited by MDE 2006).

Based on 1981 and 1982 data, Tiner and Burke (1995) estimated acreage for different wetland types found within Somerset County. The results of this analysis are found in Table 4.3.5, below.

Table 4.3.5 Acreage estimation of the different wetland types found in Somerset County based on 1981-1982 data. Source: Tiner and Burke (1995).

Wetland Type	Acreage
Estuarine Wetlands	
Non-vegetated	6,270
Emergent (salt/brackish)	53,743
Emergent (oligohaline)	885
Deciduous scrub/shrub	468
Evergreen scrub/shrub	146
Deciduous forested	360
Evergreen forested	536
Total Estuarine Wetlands	**62,408**
Palustrine Wetlands	
Emergent (tidal)	20
Emergent (non-tidal)	664
Deciduous scrub/shrub (tidal)	23
Deciduous scrub/shrub (non-tidal)	120
Evergreen scrub/shrub (non-tidal)	55
Mixed deciduous shrub-emergent (non-tidal)	31
Deciduous forested (tidal)	1,981*
Evergreen forested (tidal)	36
Deciduous forested (non-tidal)	13,873
Evergreen forested (non-tidal)	390
Mixed forested (tidal)	34
Mixed forested (non-tidal)	1,569
Dead forested/open water (non-tidal)	1
Open water (non-tidal)	358
Total Palustrine Wetlands	**19,155**
TOTAL WETLANDS	**81,563**

* Includes 23 acres along the Pocomoke River where baldcypress is co-dominant.

Land use data from 2003 developed by Maryland DNR, shows wetlands as the most prominent feature of the Monie Bay component. Approximately 929.8 hectares of wetlands are found within the limits of the Monie Bay component, which corresponds to 62% of the entire area. Forest account for 129 hectares and the presence of residential and agricultural areas within the site are minimal, totaling 14.8 hectares (Figure 4.3.8).

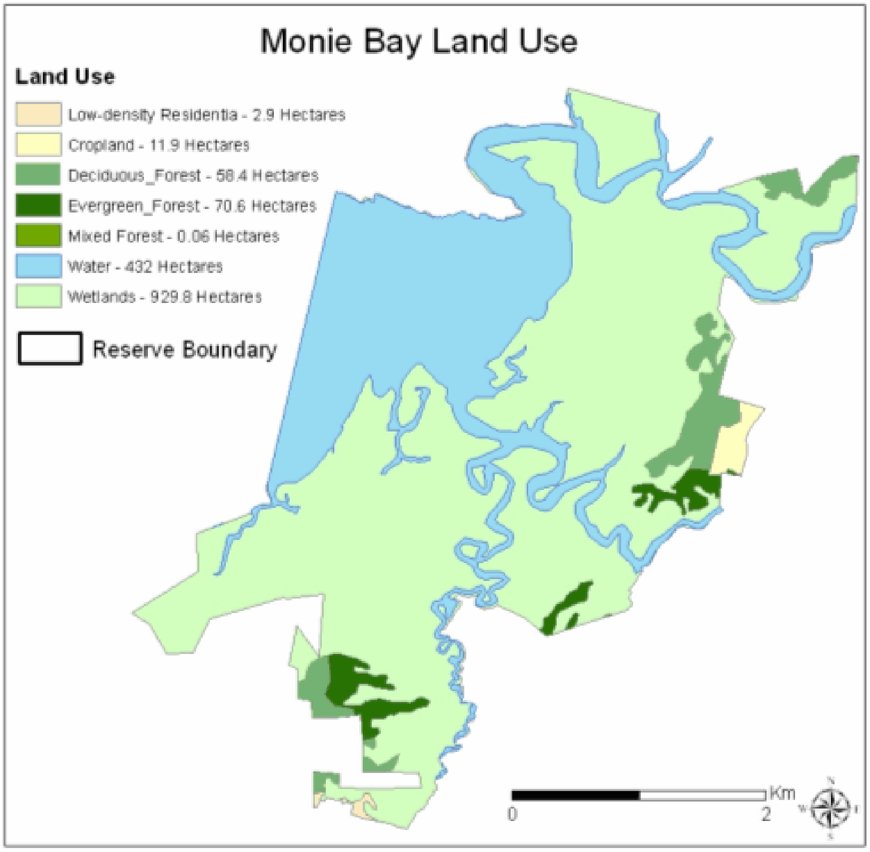


Figure 4.3.8 Land use information for the CBNERR-MD Monie Bay component for year 2003.

A comparative analysis of historical air photographs from 1938 and 1985 was conducted by Ward et al. (1988) to determine long term changes in shorelines, tidal creeks, and interior marsh areas at Monie Bay. Regarding changes in the marsh observed between 1938 and 1985 using aerial photographs, the authors noted only relatively minor changes during the 47 year-study period, which consisted largely of a gradual expansion and increased in density of tidal creek networks, with the creation of about 30 new first-order tidal creeks since 1938 (Ward et al. 1988, Kearney et al. 1994). Minor marsh deterioration was mostly limited to the southern side of Monie Bay, around the vicinity of Little Monie Creek (Figure 4.3.9). This degradation, however, was limited to declines in plant density and not major direct marsh loss (Kearney et al. 1994). The only marsh loss observed in this system was the one resulting from recession/erosion along Monie Bay's western shore as indicated above.

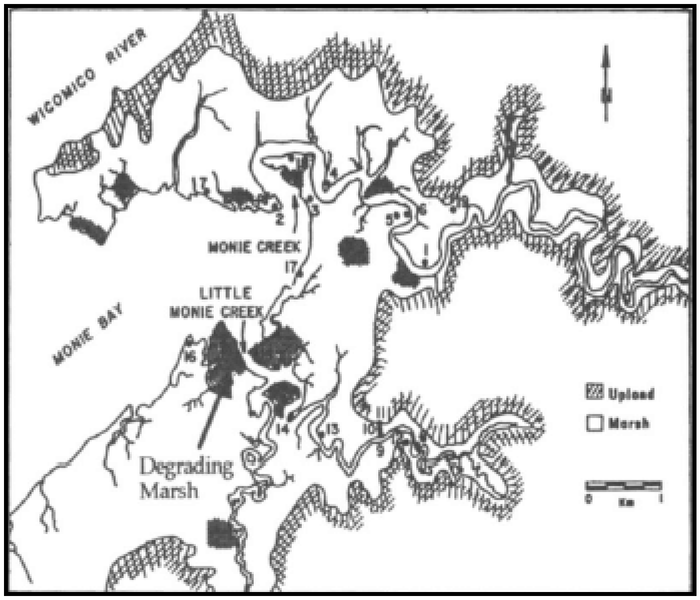


Figure 4.3.9 Monie Bay marsh deterioration areas (showing as dark pattern) as mapped from 1985 aerial photography. Source: Kearney et al. (1994).

4.3.5.4 Water use

In Somerset County, approximately 84% of the water supply that covers the needs of most of the population comes from groundwater (Werkheiser 1990). As a result, there are current concerns that with an expected increased in development the demand for water will also increase, which may impact current groundwater supply and their sustainability for the future. As indicated in section 4.3.4.2, Somerset County is underlain by seven aquifers; each of these aquifers has different characteristics, which have determined their different uses by the county as indicated in Table 4.3.6.

Table 4.3.6 Aquifers found in Somerset County, their water use and general characteristics. Source of information: Werkheiser (1990).

Aquifer	Water-use	Aquifer Characteristics
Surficial	Commercial	- Relatively thin and found throughout the county. - Water is soft to moderately hard and slightly acidic. - High dissolved iron concentrations in areas of anoxic water. - High nitrate concentrations in areas of oxygenated water and near nitrogen sources.
Pocomoke	Irrigation	- Found in the southeastern part of the county. - By 1990 there were 68 wells tapping into this aquifer. - Elevated concentrations of iron and manganese.
Manokin	Industrial	- Principal aquifer in Somerset county. - Relatively soft water low in solutes to the south and east to hard water high in chlorides towards the Chesapeake Bay. - High iron concentrations towards the northeastern part of the county.

Aquifer	Water-use	Aquifer Characteristics
		- High chloride concentrations towards the southern part of the county.
Choptank	Public supply	- High chloride concentrations.
Piney Point	Stock	- High dissolved solids.
Paleocene	Other	- Only used by the town of Crisfield as water supply. - Soft water with high concentrations of dissolved solids. - High fluoride concentrations.
Potomac	Other	- Supplies water to various municipalities along the Chesapeake Bay. - Soft water with high concentrations of dissolved solids. - High fluoride concentrations.

In an effort to evaluate the effects of projected increases in the use of these aquifers, Werkheiser (1990) ran a digital, steady-state, groundwater flow model for the Manokin aquifer near Princess Anne assuming an increase in pumpage of 600,000 gallons per day. Results indicated a decrease in water levels ranging between 15-70 feet compared to water levels measured in 1986. In addition, the time for water to move from recharge areas to the pumping well at Princess Anne was estimated between 50-300 yrs and there are concerns of saltwater contamination since water level altitudes in this aquifer are below sea level, with the lowest point near Princess Anne.

Due to the location of major sewer and water systems around Princess Anne and Crisfield, to strengthened septic regulations, and to Federal and State wetland regulations, it is expected that most of the County's development will occur around these population centers. This is also supported by the State Critical Areas restrictions on development along tidal waters (Board of County Commissioners of Somerset County 1988).

4.3.6. Water Quality

Water quality at Monie Bay is driven in part by tidal flow from the Chesapeake Bay mainstem, as well as vast tidal saltwater marshes and creeks that make up the watershed. According to the 1985 Maryland Water Quality Inventory, the water quality of Monie Bay was rated "good." Pollution was at a minimum and bacteria were found only in some areas due to agricultural and natural runoff.

By 1998 the Clean Water Action Plan classified this watershed as Category 1, a watershed not meeting clean water and other natural resources goals and therefore needing restoration. It was also classified as a Category 3, a watershed in need of protection. Failing indicators included low SAV abundance, poor SAV habitat index, and being on the 303(d) list for water quality impairment. Indicators for Category 3 include a migratory fish spawning area and a high amount of wetland-dependent species (MDE 2006).

In an effort to characterize water quality within the Monie Bay Reserve component boundaries, water quality data has been collected in Monie Bay through the Reserve's System Wide Monitoring Program (SWMP). This includes continuous and discrete sampling efforts, the results of which are presented in the following sections.

To measure water quality continuously, one long-term continuous monitoring station (CONMON – which is part of SWMP) or automated datalogger was established in 2006 along Little Monie Creek, in the Reserve's Monie Bay component (38.2086° N, 75.8046° W) and remains active through the present (Figure 4.3.10). This station monitors various water quality parameters including water temperature, specific conductivity, salinity, percent saturation, dissolved oxygen, depth, pH, and turbidity; information is recorded every 15 minutes. In addition of measuring these parameters, water samples at this CONMON station and ten other stations distributed with the Monie Bay component (Figure 4.3.10), are collected twice a month and once a month, respectively, and sent to the Chesapeake Biological Laboratory, University of Maryland Center for Environmental Studies to be analyzed for nutrients including: ammonium, nitrate/nitrate, and phosphate, total nitrogen and total phosphorus. Additional analyses per sample include chlorophyll *a*, total suspended solids, and total volatile solids. All available data that is collected through this station goes through quality assurance and quality control (QA/QC) and it is posted for public access and download in the Maryland Department of Natural resources eyesonthebay website: http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm.

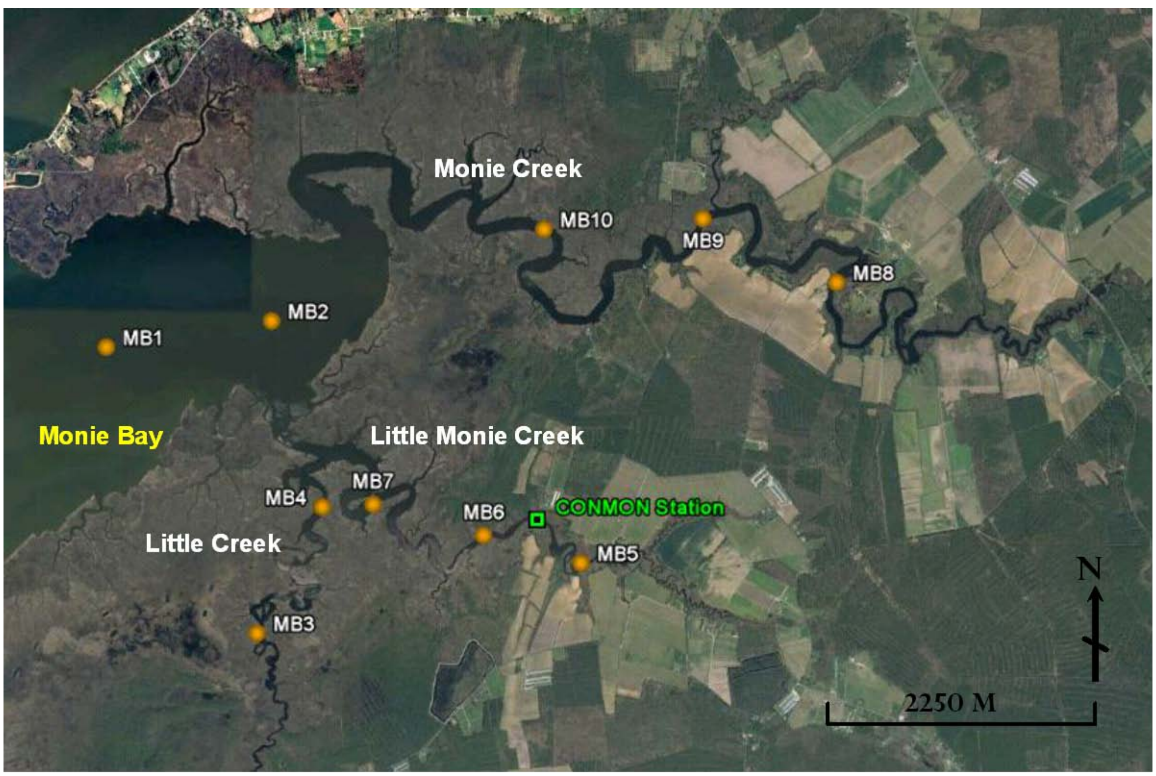


Figure 4.3.10 Location of the continuous water quality monitoring station (CONMON) at Little Monie Creek, and ten additional discrete water quality stations distributed within four different regions of the Monie Bay component: (1) Monie Bay - MB (stations MB1, MB2), (2) Monie Creek - MC (stations MB8, MB9, MB10), (3) Little Monie Creek - LMC (stations MB5, MB6, MB7), and (4) Little Creek - LC (stations MB3, MB4).

As indicated in the Otter Point Creek site profile (Section 2.3.6), the U.S. Environmental Protection Agency (EPA) Region III developed guidance and water quality criteria to address nutrient and sediment-based pollution in the Chesapeake Bay and its tidal tributaries (USEPA 2003). These water quality criteria are based on dissolved oxygen, water clarity, and chlorophyll *a*. An analysis of each of these parameters was conducted using data collected at Monie Bay through the Reserve's water quality monitoring program and will be discussed in the following sections. More information on the EPA water quality criteria is provided in Section 2.3.6 of the OPC site profile.

4.3.6.1. Dissolved oxygen (DO)

Dissolved oxygen levels for the top and bottom water layers of the overall Monie Bay area show values slightly above 5.0 mg l^{-1}, falling within the EPA criteria indicated in Table 2.3.1 (Site Profile section 2.3.6). Measured dissolved oxygen from the different Monie Bay regions range between 5.01 and 6.89 mg l^{-1} for the top water layer, and between 4.49 and 6.48 mg l^{-1} for the bottom layer (Table 4.3.7). Overall, DO values are slightly lower in the bottom layer; those from Monie Bay (MB) and Little Creek (LC) fall above the standard value of 5.0 mg l^{-1}, but this is not the case for Monie Creek (MC) and Little Monie Creek (LMC; Table 4.3.7), which happens to be the two creeks with the most residential land acreage within their watersheds (Figure 4.3.6).

Table 4.3.7 Average values of water physical/chemical parameters monitored for the Monie Bay component per four different regions: Monie Bay (MB), Monie Creek (MC), Little Monie Creek (LMC), and Little Creek (LC; Figure 4.3.10). Values were calculated based on data collected during 2006-2010; except for pH, which was calculated with data collected during 2009-2010.

Monie Bay Region	Secchi Depth (m)	Total Depth (m)	pH	Salinity (ppt)		DO (%)		DO (mg/l)		Temperature (C°)	
				Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
MB	0.78	2.22	7.55	11.94	11.96	87.56	83.95	6.89	6.59	24.1	23.8
se	0.05	0.07	0.25	0.25	0.26	2.71	2.50	0.21	0.20	0.6	0.6
MC	0.63	2.65	7.24	8.43	8.55	62.84	56.55	5.01	4.56	24.3	24.0
se	0.02	0.07	0.37	0.37	0.37	1.95	1.76	0.15	0.14	0.5	0.4
LMC	0.72	1.98	7.18	10.74	10.87	64.45	60.80	5.07	4.82	24.1	24.0
se	0.03	0.10	0.05	0.29	0.27	2.28	2.32	0.17	0.18	0.5	0.5
LC	0.78	1.98	7.38	11.48	11.48	69.42	65.90	5.47	5.23	23.8	23.7
se	0.04	0.10	0.26	0.26	0.27	2.32	2.29	0.18	0.19	0.6	0.6
Average	0.72	2.23	7.31	10.43	10.51	69.47	64.37	5.49	5.13	24.1	23.9
se	0.02	0.05	0.03	0.18	0.17	1.26	1.26	0.10	0.10	0.3	0.3

se = standard error

Even though average DO levels for Monie Bay fall above 5.0 mg l^{-1}, often times during the year DO measured at the bottom water layer was below that value (Table 4.3.7; similar results were obtained for the surface water layer). For example, MC and LMC showed that 50% or more of the DO values measured during four years in a row were below the 5.0 mg l^{-1} threshold. Similarly, DO levels at LC were also often low. Monie Bay (MB) was the only region that always showed DO levels well above the threshold (Table 4.3.8). We should, however, keep in mind that this DO criteria failure was calculated on a relatively low number of observations.

Table 4.3.8 Dissolved oxygen criteria failure at different regions within Monie Bay based on data collected from the bottom layer of the water column during April to October of 2006-2010; 5.0 mg l^{-1} is the threshold for open-water fish and shellfish use (USEPA 2007). Numbers shaded on red correspond to the regions and years where 50% or more of the DO values measured were below 5.0 mg l^{-1}.

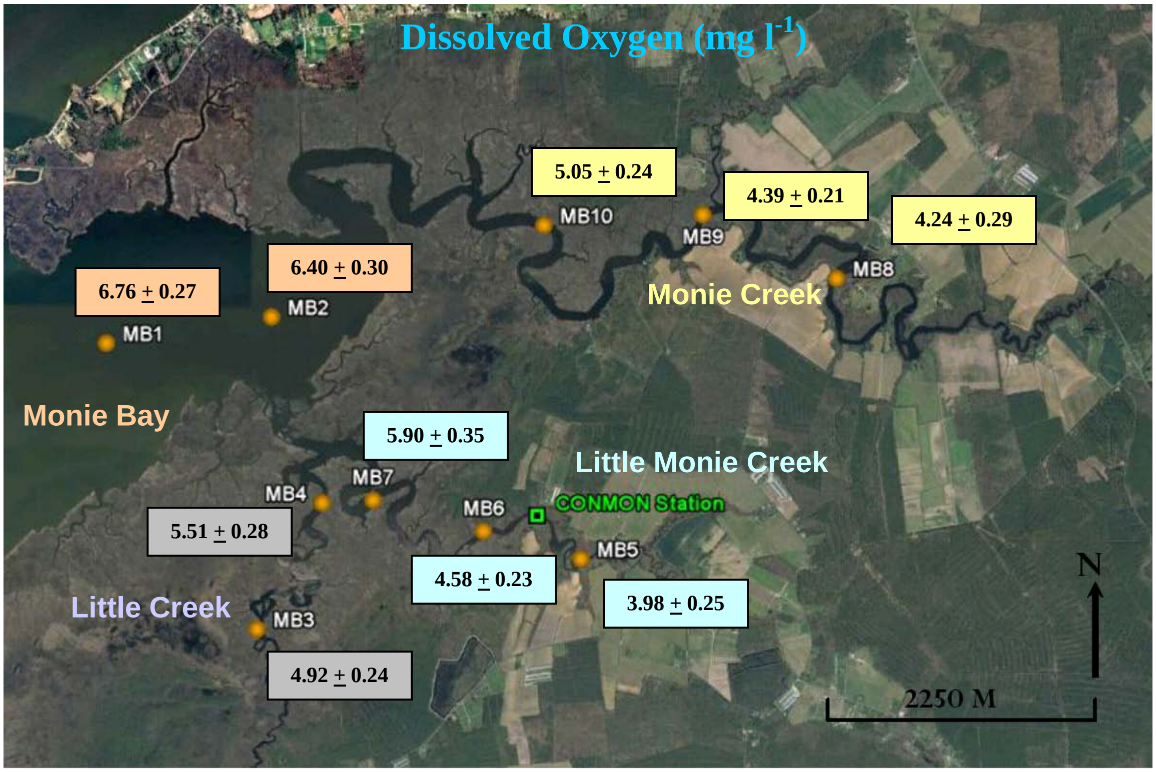
Monie Bay Region	Dissolved Oxygen Less Than 5.0 mg l^{-1} (%)				
	2006	2007	2008	2009	2010
MB	0 (12)	14 (7)	27 (15)	0 (14)	14 (14)
MC	50 (18)	92 (12)	92 (24)	62 (21)	48 (21)
LMC	39 (18)	92 (12)	75 (24)	62 (21)	57 (21)
LC	17 (12)	71 (7)	63 (16)	57 (14)	36 (14)

The numbers in parenthesis correspond to the total number of observations used to calculate the DO criteria failure.

Other parameters measured as part of the Reserve's discrete water quality monitoring at Monie Bay include salinity, temperature, and pH. Salinities at Monie Bay fall within the range of a characteristic mesohaline environment 5 – 18 ppt. With the exception of MC, where salinity averages 8.43 ppt (probably because of a larger input of freshwater – Jones et al. 1997), salinity among the different regions is very similar, ranging between 10.74 and 11.96 ppt. Salinity values, however, as low as 0.52 ppt at MC and as high as 16.80 ppt at MB have been registered for this system. Overall, salinity values are lowest in the late winter to early spring and highest in summer and fall.

A more detailed look at the spatial dissolved oxygen and salinity patterns within the Monie Bay component show a trend of increasing DO and salinity levels from the head of the creeks (MC, LMC, and LC) towards the main Monie Bay area (Figure 4.3.11). Resulting lower DO and salinity levels upstream of the creeks might be related to the higher influence of watershed runoff (spring flows) at this section of the creeks. Similarly, higher salinity levels downstream reflect the major influence of the Monie Bay proper at this portion of the creeks, which is particularly strong at LMC that may be a result of its smaller size and reduced freshwater input (Jones et al. 1997). Other factors that may influence observed spatial salinity and DO trends include creek geomorphology, spring water flow, precipitation, wind and tide induced water mixing, wetland acreage, and degree of development within adjacent watersheds. As part of a two-year study (1994-1995) in the Monie Bay tidal system Jones et al. (1997) indicated the importance of tidal flushing from the Monie Bay proper, springtime flows, and intermittent precipitation to control salinities in LMC and LC, while a stream provides freshwater to MC year-round.

The average value for water acidity (pH) and temperature at Monie Bay is 7.31 and 24 °C (75 °F), respectively; both meet state standards for healthy aquatic life. Water temperature for the three creeks is very similar; all of the creeks are relatively shallow and well mixed and seem to respond well to seasonal changes in air temperature (Jones et al. 1997). For example, lower water temperatures for all creeks persist from November through March with values ranging approximately between 6 – 14 °C, and higher temperatures occur during summer (Jones 1994).



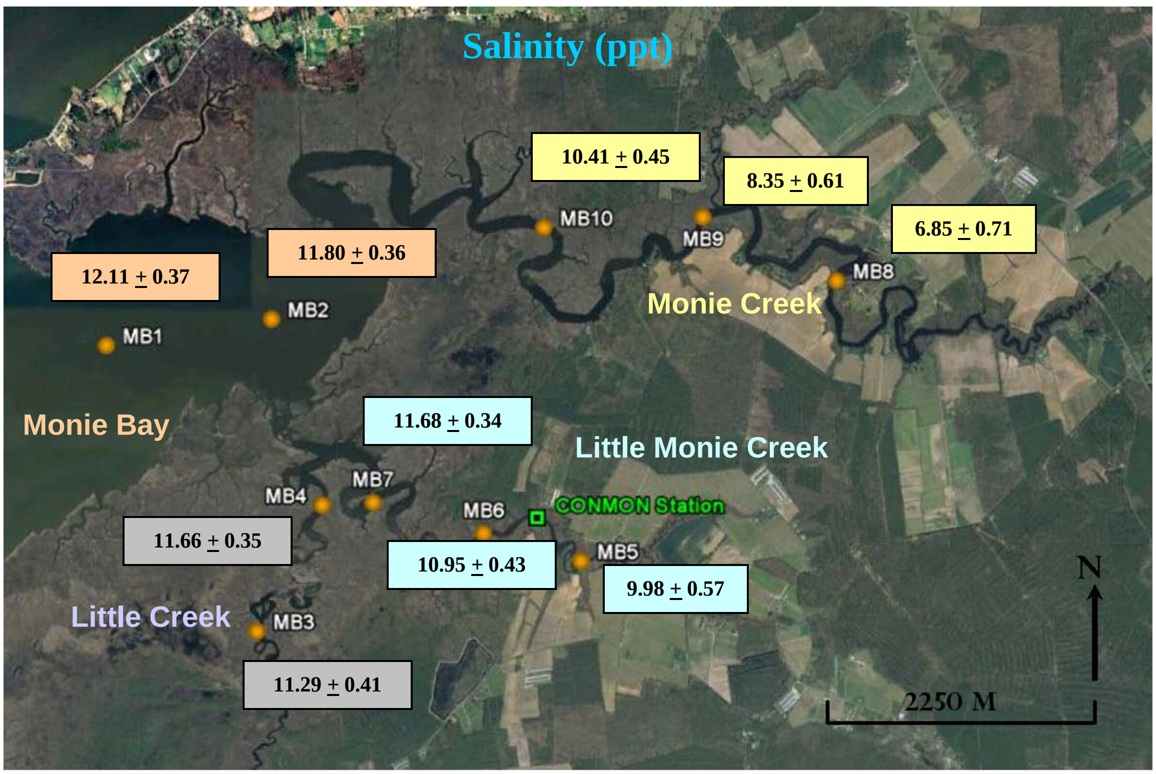
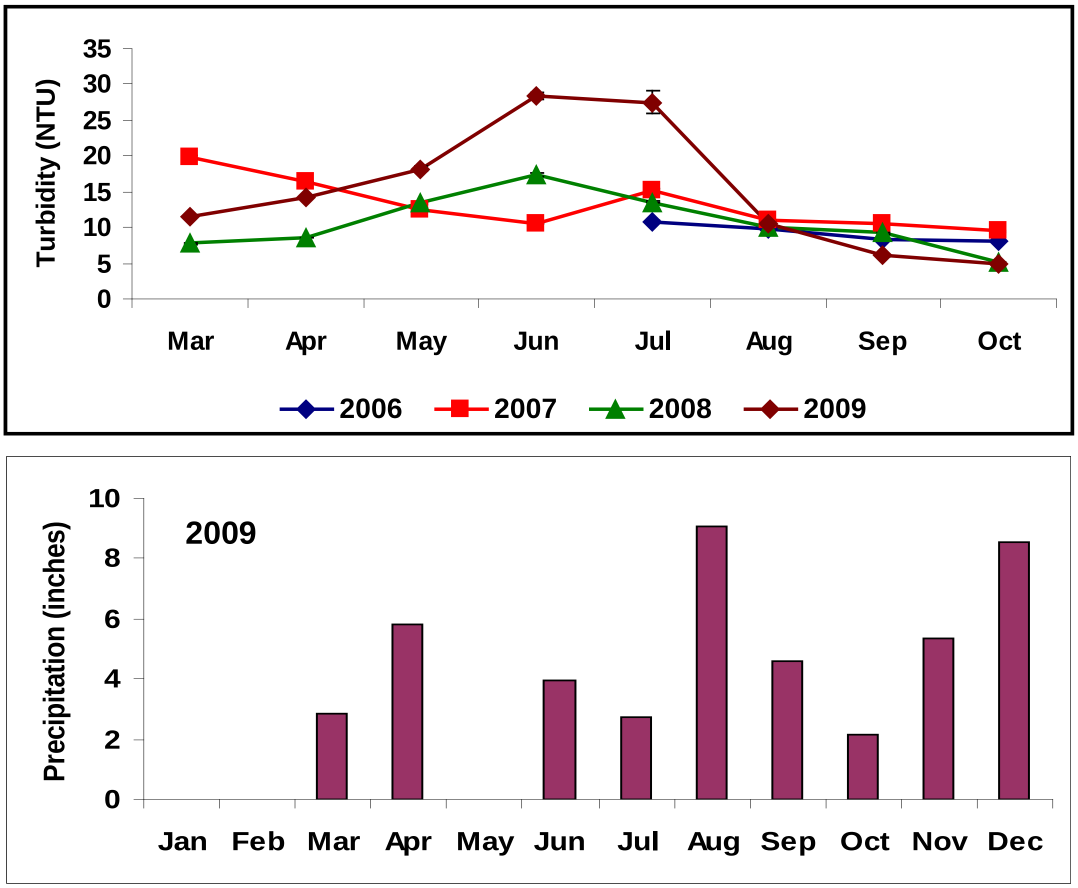


Figure 4.3.11 Spatial characterization of dissolved oxygen (mg l^{-1}) and salinity (ppt) along the different regions of the Monie Bay component: Monie Bay, Monie Creek, Little Monie Creek, and Little Creek.

4.3.6.2. Water clarity

Turbidity is considered a parameter of water clarity and it is quantified by measuring how much light is reflected from suspended particles in the water. Lower turbidity values indicate less reflection and, therefore, clearer water. In many aquatic systems, turbidity would often follow precipitation patterns and/or discharge and storm events. Turbidity measured at the CONMON station located in Little Monie Creek (see Figure 4.3.10 for location of this monitoring station) from 2006 to 2009 shows monthly average values ranging between 4.91 to 28.40 NTU (nephelometric turbidity units; Figure 4.3.12).



Turbidity data is given as NTU (Nephelometric turbidity units).

Figure 4.3.12 Monthly turbidity measured for the period 2006-2009 at the CONMON station located in Little Monie Creek, Monie Bay. Precipitation for 2009 was plotted with data collected from the Princess Anne weather station in Somerset County, Maryland.

These values do not seem high when compared with the day to day variability observed at the same monitoring station. For example, turbidity recorded during 2009 (the year with the highest values) ranged between 0 NTU during the month of September to 1,276 NTU during the month of July. Although a positive correlation between average turbidity and precipitation values it is not apparent at this station (Figure 4.3.12); daily/weekly peaks of turbidity do seem to follow precipitation/storm events. For example, in July 2009, two major thunderstorm/wind-type events were reported for the Somerset region (Table 4.3.1), which probably caused the high turbidity peaks observed during that month at LMC. How often and for how long these high turbidity peaks would last would determine the level of impacts in a particular aquatic system.

The USEPA (2003) developed water clarity criteria (based on secchi depth) for the Chesapeake Bay to establish the minimum level of light penetration required to support the survival, growth, and continued propagation of underwater bay grasses (Table 2.3.3, OPC Site Profile Section 2.3.6). As a guide, this table is included below to determine if the water clarity criteria developed is met at Monie Bay based on secchi values estimated from the ten discrete water quality stations being monitored by the Reserve at this component (Table 4.3.9).

Table 4.3.9 Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats. Monie Bay corresponds to a mesohaline marsh environment (highlighted in light blue).

Salinity Regime	**Water Clarity Criteria as Percent Light-through-Water**	**Water Clarity Criteria as Secchi Depth**								**Temporal Application**
		Water Clarity Criteria Application Depths								
		0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	
		Secchi Depth (meters) for above Criteria Application Depth								
Tidal fresh	13 %	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 – Oct 31
Oligohaline	13 %	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	April 1 – Oct 31
Mesohaline	22 %	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	April 1 – Oct 31
Polyhaline	22 %	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	Mar 1 – May 31 Sep 1 – Nov 30

Source: USEPA 2003.

The average total depth and secchi depth (calculated from a 4-year data record: 2006-2010) for the four Monie Bay regions ranged between 1.98 m (± 0.10) and 2.65 m (± 0.07), and between 0.63 m (± 0.02) and 0.78 m (± 0.05), respectively. Based on this information and Table 4.3.7, none of the regions at Monie Bay meets the water quality criteria for the adequate growth of shallow-water grasses; the average secchi depth throughout Monie Bay is lower than the required 1.9 m of a mesohaline environment of approximately 2.0 m of water depth.

4.3.6.3. Chlorophyll *a*

Chlorophyll *a* has been used for years as an indirect quantitative indicator of the phytoplankton community in a water body. It is also commonly used as an indicator of water quality, where high chlorophyll *a* concentrations are associated to low water quality. As cited in USEPA (2003) the eutrophic status of a system could be characterized by its mean chlorophyll *a* concentration (Table 2.3.4, OPC Site Profile Section 2.3.6). Based on this Table, a marine system with chlorophyll *a* values greater than 7 ug l^{-1} is characterized as eutrophic. Therefore, knowing that the average chlorophyll values for the four Monie Bay regions range between 7.1 ug l^{-1} (± 0.4) at LC and 13.7 ug l^{-1} (± 0.9) at MC, the Monie Bay system could be considered as eutrophic.

An additional water quality chlorophyll *a* criteria also based on the concentration of total suspended solids, habitat type (fresh, oligohaline, mesohaline, and polyhaline), and total water depth is presented in Table 4.3.10 (USEPA 2003).

Table 4.3.10 Chlorophyll *a* concentrations (µg liter^{-1}) that reflect attainment of the Chesapeake Bay water clarity criteria given a range of total suspended solids concentrations and shallow-water application depths. Areas in gray indicate exceedance of the water clarity criteria. Source: USEPA (2003).

Total Suspended Solids (mg liter^{-1})	Tidal-Fresh and Oligohaline			Mesohaline and Polyhaline		
	Water-Column Depth (meters)					
	0.5 m	1 m	2 m	0.5 m	1 m	2 m
5	199	71	9	122	34	
10	171	43		95	8	
15	144	16		68		
20	116			42		

Monie Bay Region	Average Water Column Depth (m)	Average Total Suspended Solids (mg l^{-1})	Average Chlorophyll *a* concentration (µg liter^{-1})
MB	2.22 ± 0.07	39.2 ± 3.0	9.4 ± 0.5
MC	2.65 ± 0.07	33.5 ± 1.9	13.7 ± 0.9
LMC	1.98 ± 0.10	39.5 ± 2.2	9.8 ± 0.4
LC	1.98 ± 0.10	36.1 ± 2.6	7.1 ± 0.4

Average values were calculated from a 4-year water quality monitoring data set 2006-2010 collected for Monie Bay by the Chesapeake Bay National Estuarine Research Reserve in Maryland.

Considering the chlorophyll *a* criteria and Monie Bay water quality information presented in Table 4.3.10, the conditions throughout Monie Bay exceed the water quality criteria. This is particularly reflected by the relatively high total suspended solids recorded for this system. The highest values are found at LMC and MB, followed by LC and MC (Table 4.3.10).

The overall average chlorophyll *a* concentrations measured at Monie Bay were below the threshold of 15 µg l^{-1} for each of the four regions. Monie Creek is characterized by higher chlorophyll *a* concentrations than MB, LMC, and LC; the latter with the lowest value of all (Table 4.3.10). For both, MC and LMC chlorophyll *a* decreases downstream; with the highest values found at monitoring stations 8 and 5, respectively (Figure 4.3.13).

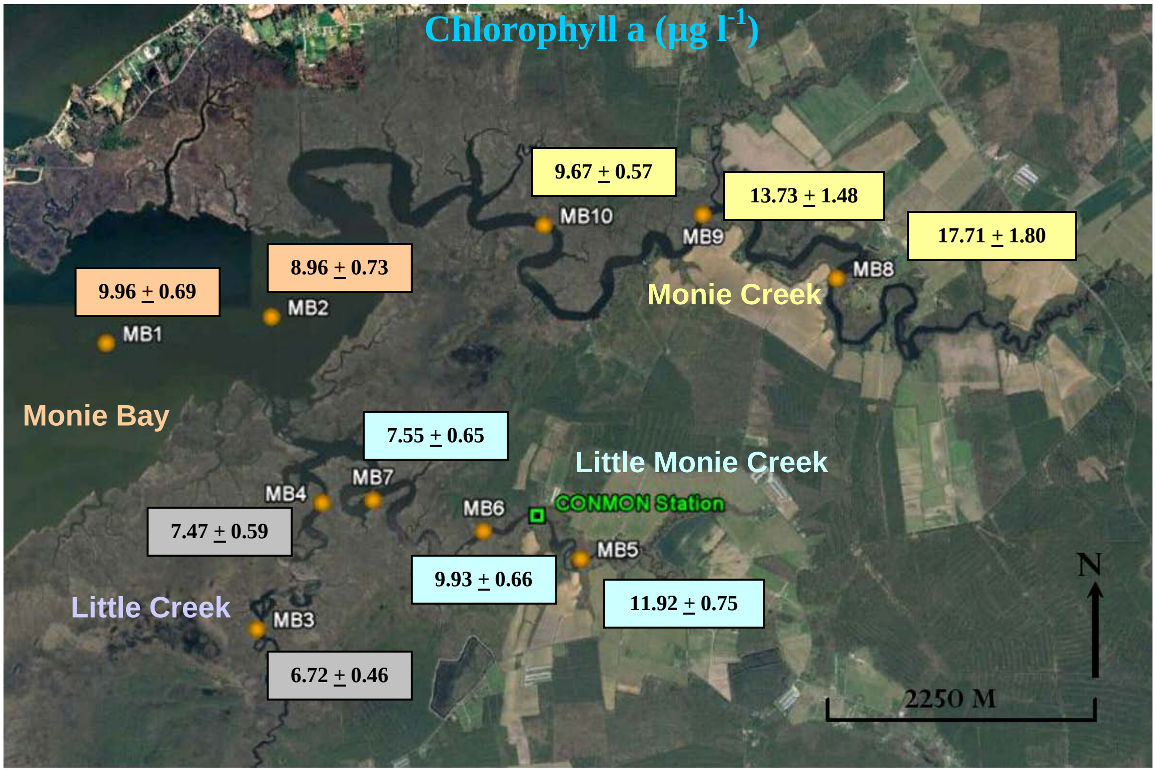


Figure 4.3.13 Spatial characterization of chlorophyll *a* (µg l^{-1}) along the different regions of the Monie Bay component: Monie Bay, Monie Creek, Little Monie Creek, and Little Creek.

Although chlorophyll *a* levels were generally low throughout the Monie Bay system, some peaks were evident in some of the tributaries particularly MC, which showed during 2006, 2008 and 2009 chlorophyll *a* levels above the threshold value at more than 25% of the yearly observations. In April 4, 2008 there was a chlorophyll *a* peak at MC that reached a value of 51.1 µg l^{-1}, which is above the concentration that indicates significant algal blooms. LMC also experienced some high chlorophyll *a* concentrations in comparison with the other regions; LC was the region with the lowest values throughout (Table 4.3.11).

Table 4.3.11 Chlorophyll *a* criteria failure at different regions within Monie Bay based on data collected during April to October of 2006-2010; 15 µg l^{-1} is the threshold above which an aquatic system may start experiencing algal bloom-related impacts. Numbers shaded on red correspond to the regions and years where 25% or more of the chlorophyll *a* values measured were above 15 µg l^{-1}.

Monie Bay Region	Chlorophyll *a* Readings Greater than 15 µg l^{-1} (%)				
	2006	2007	2008	2009	2010
MB	33 (12)	0 (7)	0 (13)	7 (14)	7 (14)
MC	39 (18)	0 (11)	25 (20)	25 (20)	24 (21)
LMC	17 (18)	9 (11)	11 (19)	19 (21)	5 (21)
LC	8 (12)	0 (8)	0 (13)	0 (14)	0 (14)

The numbers in parenthesis correspond to the total number of observations used to calculate the Chla criteria failure.

4.3.6.4. Nutrients

Nitrogen and other forms of nutrients from runoff, agriculture fields, manure, septic systems, and wastewater treatment plants contribute to water quality degradation within the Monie Bay component. As indicated in previous sections, the Monie Bay component receives freshwater inputs from three creeks MC, LMC, and LC. These differ in flushing times (MC: 1.2, LMC: 1.9, and LC: 12.4 days), sub-watershed size (MC: 45.0 km^2, LMC: 17.9 km^2, LC: 9.4 km^2), and land use: residential septic systems and poultry operations (Monie Creek), crop fertilizer (Little Monie Creek), and wetlands/forest (Little Creek). How nutrient concentrations vary within and among these creeks and impact the Monie Bay system has been studied through different projects (Jones 1994, Cornwell et al. 1994, Jones et al. 1997, Apple et al. 2004, Fertig et al. unpublished data). Water quality including nutrients has also been monitored by the Reserve's research program since 2006. Results and highlights from several of these studies and from data collected through the CBNERR-MD monitoring program will be discussed in the following sections.

Nutrients enter Monie Bay and its creeks from multiple locations, especially to upstream Monie Creek and the mouth of Monie Bay (Apple et al. 2004, Fertig et al. unpublished data). Fertig et al. (unpublished data) indicates that nitrogen entering the Monie Bay system is derived from both 19 poultry houses delivering manure from the Monie Creek watershed (~8.6×10^5 kg N yr^{-1}; the approximate equivalent to ~200,000 people yr^{-1}) and human/animal wastes from Wicomico River and its watershed (including wastewater facilities servicing ~29,500 people, ~7,000 septic systems, and estimated poultry manure inputs of 3.7×10^6 kg N yr^{-1}). Other sources of nutrients are derived from agriculture fields as runoff (Cornwell et al. 1994, Jones et al. 1997).

Results of average nutrient concentrations for the different regions within Monie Bay are presented in Table 4.3.12. Total nitrogen (TN) and total phosphorus (TP) concentrations in all regions fall above threshold values for those parameters: 0.01 mg l^{-1} and 0.5 mg l^{-1}, respectively. Monie Creek has the highest TN and TP concentrations of the entire Monie Bay system while LC has the lowest.

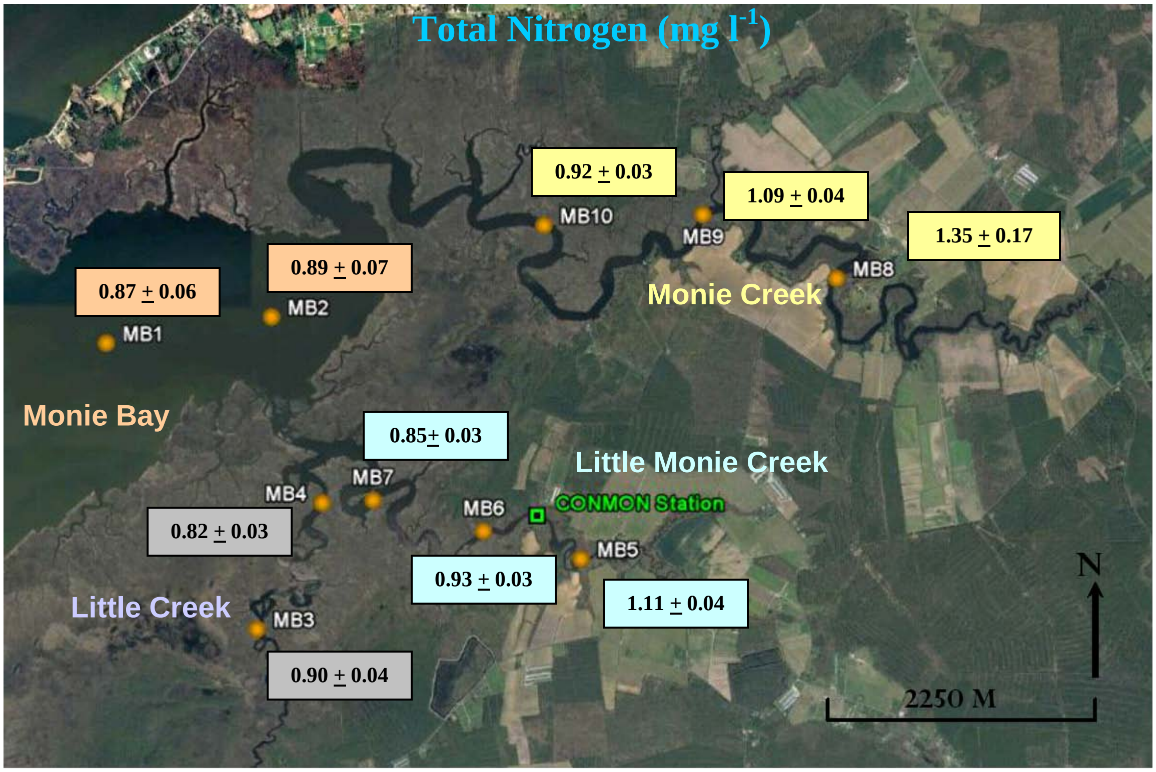
Table 4.3.12 Average nutrient values monitored for the Monie Bay component at four different regions: Monie Bay (MB), Monie Creek (MC), Little Monie Creek (LMC), and Little Creek (LC). Values were calculated based on data collected during 2006-2010.

Monie Bay Region	Total N mg N l^{-1}	Total P mg P l^{-1}	NO_3 mg N l^{-1}	NH_4 mg N l^{-1}	NO_2 mg N l^{-1}	PO_4 mg P l^{-1}
MB	0.88	0.0642	0.0412	0.017	0.0035	0.0036
standard error	0.05	0.0180	0.0143	0.001	0.0010	0.0001
MC	1.12	0.0805	0.0196	0.028	0.0026	0.0111
se	0.06	0.0043	0.0044	0.003	0.0005	0.0014
LMC	0.96	0.0729	0.0274	0.027	0.0025	0.0151
se	0.02	0.0056	0.0057	0.003	0.0003	0.0038
LC	0.86	0.0412	0.0232	0.027	0.0021	0.0039
se	0.03	0.0013	0.0078	0.004	0.0002	0.0003
Average	0.97	0.0671	0.0270	0.026	0.0026	0.0094
se	0.02	0.0042	0.0039	0.002	0.0003	0.0012

Total nitrogen and total phosphorus concentrations were highest in upstream MC (Figure 4.3.14) where terrestrial sources of nitrogen such as rural residential and poultry inputs were available from within the watershed (station 8: 1.35 ± 0.17 mg l^{-1} total nitrogen, 0.1091 ± 0.0099 mg l^{-1} total phosphorus). Concentrations generally decline from the upper reaches of Monie Bay tidal creeks to the open bay water because of dilution and biogeochemical processing. The lowest TN and TP concentrations were found downstream LC (station 4: 0.82 ± 0.03 mg l^{-1} total nitrogen, 0.0407 ± 0.0019 mg l^{-1} total phosphorus; Figure 4.3.14), which is mostly surrounded by forests and wetlands. MC had higher TN concentrations than LMC and both creeks had higher TN and TP concentrations than LC or Monie Bay (Table 4.3.12).

Similar to some of the observations mentioned above, Jones (1994), Jones et al. (1997), and Apple et al. (2004) determined that within the Monie Bay system, nutrient levels in general followed a consistent gradient where MC>LMC>>LC, with MC and LMC being very close. In addition, LMC had overall higher nutrient concentrations than LC, and this difference was attributed to differences in the watersheds of the two creeks. LMC and MC were consistently higher in dissolved inorganic nitrogen (DIN), dissolved inorganic phosphorus (DIP), and chlorophyll *a* than LC, with the greatest difference in DIP.

Fertig et al. (unpublished data) determined that dissolved oxygen concentrations were negatively correlated with total nitrogen ($r = -0.51$, $p < 0.0001$) and total phosphorus ($r = -0.54$, $p < 0.0001$), but not with chlorophyll *a*.



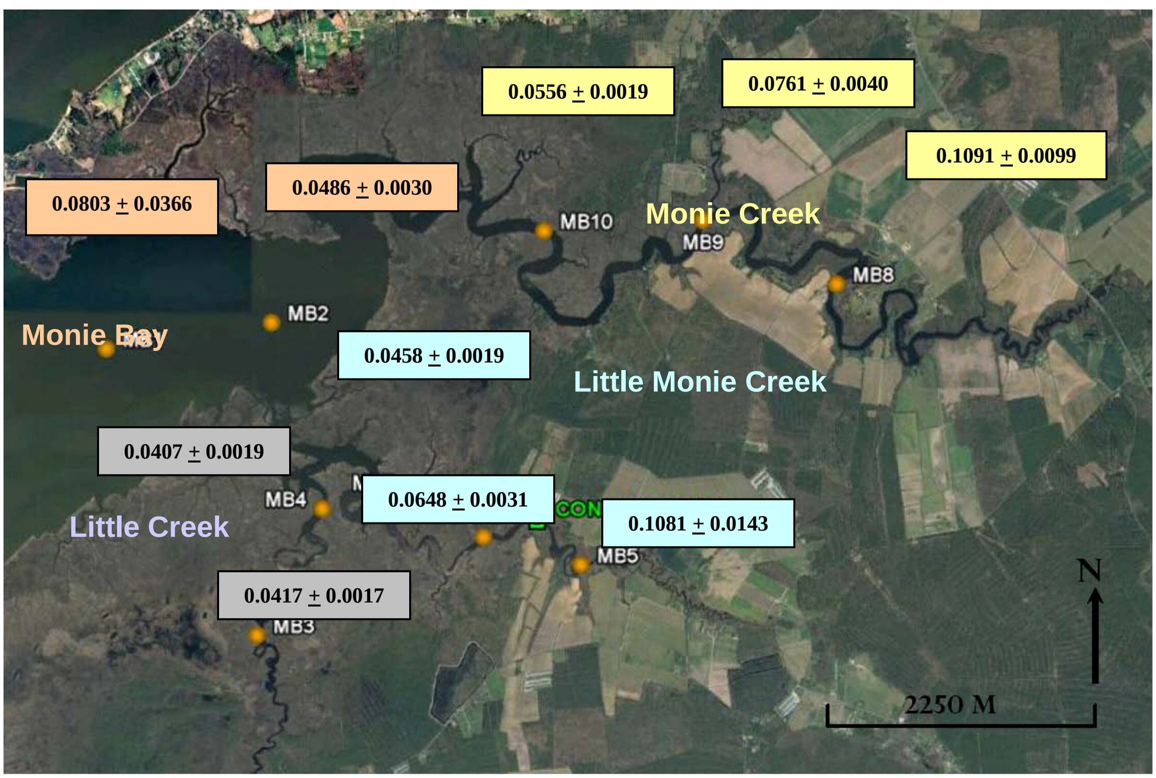


Figure 4.3.14 Spatial characterization of total nitrogen and total phosphorus (mg l^{-1}) along the different regions of the Monie Bay component: Monie Bay, Monie Creek, Little Monie Creek, and Little Creek.

For the interest of comparison, results of nutrient concentrations, biological parameters, and watershed characteristics (using the same sampling sites as indicated in Figure 4.3.14) from a two-year study (2000-2002) by Apple et al. (2004) are presented below in Table 4.4.13 and Figure 4.3.15.

Table 4.3.13 Nutrient concentrations, biological parameters, and watershed characteristics for the three tidal creeks and open bay of the Monie Bay system. Values are derived from 2-year means ± SE (n). Source: Apple et al. (2004).

	MC		LMC		LC		OB		*n*
Depth (m)	3.3 ± 0.2	(29)	3.1 ± 0.2	(25)	2.0 ± 0.1	(18)	2.2 ± 0.1	(14)	86
TDN (μM)	40.6 ± 2.1	(65)	40.1 ± 2.8	(58)	26.8 ± 1.6	(38)	28.1 ± 1.7	(40)	201
TDP (μM)	0.7 ± 0.08	(65)	0.8 ± 0.12	(58)	0.2 ± 0.03	(38)	0.3 ± 0.03	(40)	201
DON (μM)	36.7 ± 1.7	(65)	35.6 ± 1.9	(58)	21.6 ± 1.9	(38)	19.8 ± 1.8	(40)	201
NH_4^+ (μM)	2.3 ± 0.314	(65)	3.0 ± 0.428	(58)	2.1 ± 0.2	(38)	1.7 ± 0.178	(40)	201
NO_x (μM)	4.5 ± 0.859	(65)	4.8 ± 1.045	(58)	3.1 ± 0.64	(38)	6.6 ± 1.299	(40)	201
PO_4^{3-} (μM)	0.2 ± 0.05	(65)	0.3 ± 0.065	(58)	0.2 ± 0.1	(37)	0.0 ± 0.006	(40)	200
Salinity	6.9 ± 0.4	(75)	9.9 ± 0.3	(62)	11.6 ± 0.3	(38)	12.1 ± 0.3	(42)	217
DOC (mg L^{-1})	11.5 ± 0.5	(71)	8.9 ± 0.4	(59)	7.7 ± 0.3	(36)	6.0 ± 0.2	(39)	205
DOC : TDN	24 ± 2	(62)	20 ± 1	(55)	27 ± 2	(36)	20 ± 1	(37)	190
TDN : TDP	103 ± 22	(60)	84 ± 8	(55)	170.0 ± 27	(34)	130 ± 15	(35)	184
$a350^{*1}$	20 ± 0.7	(43)	17 ± 0.7	(35)	15 ± 1	(19)	12 ± 0.9	(22)	119
BA (10^6 cells mL^{-1})	11.8 ± 0.7	(74)	13.3 ± 1.0	(62)	12.8 ± 1.4	(35)	11.5 ± 1.0	(42)	213
BP (μg C L^{-1} h^{-1})	1.8 ± 0.1	(59)	2.6 ± 0.2	(48)	1.5 ± 0.1	(29)	1.1 ± 0.1	(33)	169
Filtered BP (μg C L^{-1} h^{-1})[3]	1.0 ± 0.1	(59)	1.4 ± 0.1	(48)	1.0 ± 0.2	(29)	0.6 ± 0.1	(33)	169
% filtered BP[2]	55.6	(59)	53.8	(48)	66.7	(29)	54.5	(33)	169
Watershed size (km^2)	45		17.9		9.4		72.3		
Agriculture[4]	23		25		<1		16		

[1] Specific absorbance at 350 nm × 10^3.
[2] BP for the AP15 filtered fraction.
[3] Percentage of total BP attributed to the AP15 filtered fraction.
[4] Percentage of agricultural land use within each watershed. The open bay watershed is composed of adjacent marshes and the watershed from each creek.
MC = Monie Creek, LMC = Little Monie Creek, LC = Little Creek, OB = open bay, TDN = total dissolved nitrogen, TDP = total dissolved phosphorus, DON = dissolved organic nitrogen, NO_x = NO_3^- + NO_2^-, DOC = dissolved organic carbon, BA = total bacterial abundance, BP = total bacterioplankton production.

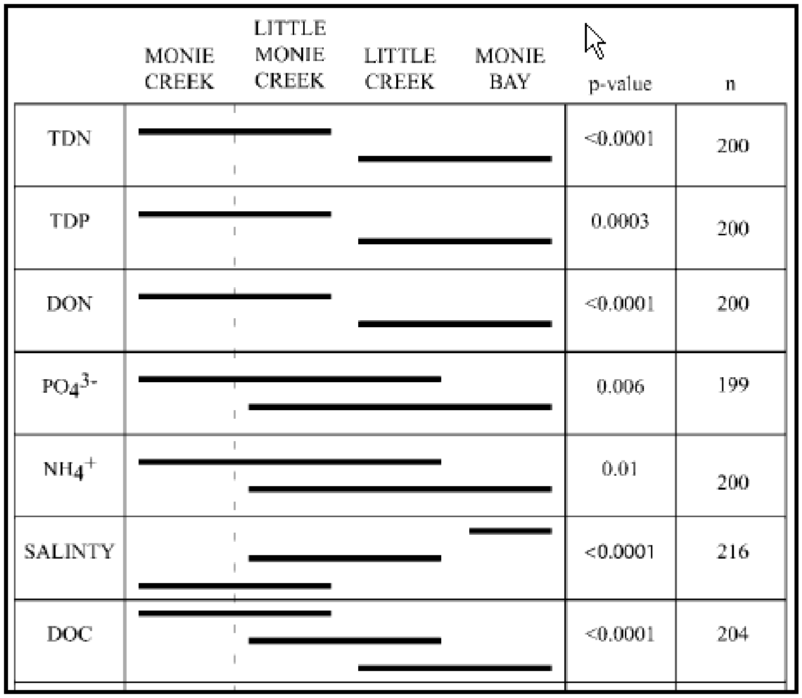


Figure 4.3.15 Comparisons among the three tidal creeks and open bay of the Monie Bay system. For each parameter the bar height represents the magnitude of a 2-year mean (2000-2002). Means that are statistically similar share the same bar height. Parameters are defined in Table 4.3.13.

Due to patterns of water circulation and flushing, Monie Bay seems to act as both a nutrient source to its tributaries (transporting nutrients among its creeks) and as a nutrient sink for other watersheds (receiving septic and wastewater nitrogen at its mouth). According to Fertig et al. (unpublished data), the enrichment of oyster $\delta^{15}N$ in downstream areas compared to upstream areas in Monie Bay, LC, and LMC indicates that nitrogen from human and/or animal waste sources is transported upstream. The mouths of Monie Bay and Wicomico River mix, and enriched oyster $\delta^{15}N$ values there (MB station 1) were likely influenced by Wicomico River watershed nitrogen sources such as septic systems, wastewater effluents or poultry (Table 4.3.14).

Table 4.3.14 Relative inputs to Monie, Wicomico, and Delmarva Peninsula watersheds from sewage, septic, and poultry manure sources. Poultry Manure 'People Equivalents' are estimated based on the assumed generation 1.9 kg total nitrogen (TN) chicken^{-1} yr^{-1} and 4.3 kg TN person^{-1} yr^{-1}. Source of table: Fertig et al. (unpublished data).

	Monie Bay	Wicomico River	Delmarva Peninsula	References
Human Population (2002)	2,576	28,028	1,172,776	MDP 2000 U.S. Census 2000 MD DNR 2009
Average Annual Chicken Population (2002)	828,138	1,940,209	109,550,814	Naber and Bermudez 1990 USDA 2002 USDA 2005
Chicken Manure 'People Equivalents'	365,050	855,260	48,290,918	Naber and Bermudez 1990 US EPA 2002
Sewage Systems (2002)	0	3	27	A. Brockenbrough, VDEQ, pers. comm. P. Hansen, DNREC, pers. comm. MDE 2009
Sewage Inputs (kg TN yr^{-1})	0	196,212	556,090	Crites and Tchobanoglous 1998 MD DNR 2009 US EPA 2002 Tchobanoglous et al. 2003
Septic Systems	699	7,233	181,953	A. Butler, MDP, pers. comm. J. Davis, VDHES, pers. comm. J. Volk, DNREC, pers. comm.
Septic Inputs (kg TN yr^{-1})	10,304	112,112	3,133,864	US EPA 2002 Tchobanoglous et al. 2003
Manure Inputs (kg TN yr^{-1})	1,576,353	3,693,170	208,528,964	Lichtenberg et al. 2002 Parker and Li 2006 USDA 2005

Nitrogen present in the waters of Monie Bay flushes into the tributary creeks, where it seems to have more impact on LMC and LC than on MC. Since the flushing time in MC was roughly six times greater (12.4 days) than LC and LMC (1.2 days and 1.9 days, respectively), nitrogen sources from its watershed (mainly poultry and septic) had a greater impact on water quality there, than it did in the respective watersheds of LMC and LC. Likewise, poultry, septic, and wastewater nitrogen sources that entered the mouth of Monie Bay encroached more upon LMC and LC than MC. Monie Bay itself is likely influenced by allochthonous nitrogen sources (e.g., the Wicomico River) transported by bottom layer circulation patterns typical of Chesapeake Bay tributaries. For example, both wastewater effluent from the Patuxent River watershed (Fisher et al. 2006) and nutrients in Chesapeake Bay from other tributary watersheds (Testa et al. 2008) act as nutrient sources to the Patuxent River through this circulation and transport pattern.

Based on a transect study conducted in LMC from headwaters to the open bay, agricultural runoff nearly doubles the concentration of total nitrogen (TN) and total phosphorus (TP) along the creek axis. This seems to indicate that nutrients from agricultural land use enters these creeks upstream, and are considerably diluted as they pass through the marsh and are subject to tidal mixing. TP concentrations in LMC were four-fold higher than that of LC, and TN was elevated two- to three-fold higher (Jones et al. 1997). Similarly, Apple et al. (2004) determined that peaks of nutrient enrichment within Monie Bay and its creeks are highly determined by the schedule of fertilizer applications within the watershed, which generally occur in late March to early April, followed by another application in June.

The main driver of nutrient delivery to the Monie Bay system was identified as freshwater input, which in this area is mainly determined by runoff after rains and storm events. Subsurface transport of particularly phosphorus may also be important (Apple et al. 2004).

Denitrification in Monie Bay creek sediments

Potential nitrogen removal from the tributaries of Monie Bay by denitrification seems to be low (12.1% to 19.5%) due in part to quick flushing times and high non-advective exchange (383,916 $m^3 d^{-1}$ in LMC; Table 4.3.15). Monie Creek had both the highest total nutrient load and estimated nitrogen removal, both of which were influenced by its watershed area, water volume, mean daily precipitation, slow flushing time (Table 4.3.15), the small non-advective exchange with Monie Bay (almost half of that of LMC), and land use (including rural residences and poultry feeding operations). In comparison to its creeks, Monie Bay is larger than any of its tributaries and more saline even though it received the highest mean daily precipitation, since its watershed area was the sum of all three tributaries, but nitrogen removal could not be calculated for this region as calculations relied upon non-advective exchange with Monie Bay (Fertig et al. unpublished data).

Less than 20% of nitrogen was calculated to be potentially lost via denitrification in each of the tributary creeks (Table 4.3.15) based on the relationship between nitrogen removal by denitrification and residence time of various aquatic ecosystems (Seitzinger et al. 2006, Fertig et al. unpublished data).

Table 4.3.15 Simple conservative box model for calculations of flushing time, non-advective exchange (E) and potential nitrogen removal in Monie Bay and its three tributary creeks. Salinity was measured in 2006 while daily precipitation was averaged over 1971-2000. Source: Fertig et al. (unpublished data).

Creek	Volume (m^3)	Mean Salinity (ppt)	Mean Daily Precipitation ($m^3 d^{-1}$)	Watershed area (m^2)	E ($m^3 d^{-1}$)	Flushing time (d)	Expected N removal (%)
Monie Bay	13,495,457	11.7	218,459	7.2×10^7			
Little Creek (wetlands)	418,984	10.8	28,403	9.4×10^6	354,214	1.2	12.1
Little Monie Creek (crop agriculture)	726,748	10.2	54,086	1.8×10^7	383,916	1.9	13.3
Monie Creek (septic/manures)	2,481,109	7.0	135,970	4.5×10^7	199,998	12.4	19.5

4.4. BIOLOGICAL AND ECOLOGICAL SETTING

Relatively recent studies have provided substantial new information about the estuarine ecology of the tidal creeks and embayments connected to the tidal marsh and upland habitats of the Monie Bay Reserve component. As described in earlier sections, three main tidal creeks (Monie Creek, Little Monie Creek, and Little Creek) penetrate into the Monie system through the marshes near their mouths and into the forested and agricultural lands near their freshwater sources. These tidal creeks empty into an outer bay which connects drainage from Monie Bay as well as Wicomico and Nanticoke Rivers, to Chesapeake Bay proper. The three tidal creeks and adjacent outer bay form an integrated Monie Bay estuarine system.

The general landscape of the Monie Bay component is flat, only a few feet above sea level, and it is mainly comprised of open estuarine waters and tidal creeks, marshes, and upland pine forests. Most of the marsh could be classified into low and high marsh and both tend to be brackish. The upland wooded sections are dominated by loblolly pine with greenbrier and myrtle understory. These main habitats found within the Monie Bay CBNERR-MD component will be discussed in more detail in the following sections.

4.4.1. Brackish Marsh

The Monie Bay marsh system is considered a typical late youth to mature marsh. The species composition is influenced by changes in the marsh surface microtopography, which controls the frequency and duration of flooding by tidal waters. The high marsh is the area that gets flooded less often and its soil characteristics reflect somewhat its distance to the more high energy tidal channels or open water (Ward et al. 1998).

According to Ward et al. (1988), the marshes of Monie Bay are composed of three different sub-environments: 1) bank marshes like the ones found surrounding the perimeter of the Monie Bay proper; these are exposed to high wave action, which may cause bank erosion, but also allows for the deposition of storm overwash deposits composed of mainly sandy sediments. 2) Tidal channel bank marshes found along the three tributary creeks of Monie Bay; these are frequently flooded by the tides and are mainly composed of fine grained silts and clays. 3) Back marsh areas, which are flooded less frequently, are highly organic, and are composed of very fine grained sediments.

Marsh surface elevation at Monie Bay can vary significantly across marsh areas (>10 cm within a square meter; Kearney et al. 1994), but changes are generally random, and lack the classic levee to interior marsh microtopography reported for other marshes (Delaune et al. 1983).

Overall, the marsh vegetation in Monie Bay is characteristic of East coast mid-salinity regimes and the species distribution in this area is mainly a response to random changes in marsh microtopography and, therefore, lacks the typical zonation away from tidal creeks or shorelines characteristic of open coast salt marshes (Frey and Basan 1985). The dominant marsh plants in Monie Bay include *Spartina alterniflora* (smooth cordgrass), *Spartina cynosuroides* (big cordgrass), *Spartina patens* (salt meadow cordgrass), and *Schonoplectus americanus* (American bulrush); while in areas less frequently flooded, *Juncus roemerianus* (needlegrass rush) *Distichlis spicata* (marsh spikegrass) and *Phragmites australis* (common reed) are also common (Kearney et al. 1994). A more complete list of the species that can be found in the wetlands of Monie Bay is given in Appendix II.

Different from most salt marshes, mesohaline marshes such as the ones characteristic of Monie Bay have a greater abundance of species utilizing C3 photosynthesis to fix carbon, in addition to C4 plants. In Monie Bay *S. alterniflora* is a typical C4 plant, but other species such as *J. roemerianus*, *P. australis*, and *Atriplex patula* (spearscale) are considered C3 plants; Table 4.4.1

shows a list of some of the most common C3 and C4 marsh species found in Monie Bay. As a result of this, consumers in this marsh system seem to reflect the importance of these C3 plants as part of their food sources (Stribling and Cornwell 1997).

Table 4.4.1 Common C3 and C4 marsh species found at Monie Creek, Monie Bay. Modified from Stribling and Cornwell (1997).

Marsh Species	
C4	**C3**
Spartina alterniflora	*Amaranthus cannabinus*
Spartina cynosuroides	*Juncus roemerianus*
Spartina patens	*Ptilimnium capillaceum*
Distichlis spicata	*Juncus gerardi*
	Scirpus americanus
	Polygonurn punctatum
	Atriplex patula
	Phragmites australis

Estimates of wetland acreage for the entire Monie Bay watershed were calculated by Maryland DNR. Results of this mapping effort are presented in Table 4.4.2, below. Based on data between 1991 and 2004, for this watershed, Walbeck (2005) reported a slight loss in wetlands.

Table 4.4.2 Acreage estimation of different wetland types found in Monie Bay watershed. Estimates are based on GIS data from Maryland DNR. Source: MDE (2006).

Wetland Type	**Acreage**
Estuarine Wetlands	
Emergent	6,186
Scrub/shrub	90
Forested	348
RF	91
Unconsolidated shore	14
Total Estuarine Wetlands	**6,729**
Palustrine Wetlands	
Emergent	481
Scrub/shrub	927
Forested	5,438
Unconsolidated bottom	17
Farmed	27
Total Palustrine Wetlands	**6,890**
TOTAL WETLANDS	**13,619**

For the purpose of this document, three distinctive habitats within the Monie estuary will be discussed in more detail in the following sections. These habitats include subtidal and open water (including submerged aquatic vegetation), low marsh, and high marsh.

4.4.1.1 Subtidal and open water

The Monie Bay subtidal and open water habitat consists of mostly barren sediment and the water column; although in some locations the presence of the underwater grass *Ruppia maritima* (widgeon grass) has been reported as indicated below. In comparison with the top layer of the marsh, subtidal sediment is characterized by lower levels of organic matter, which may be due to a significant input of inorganic particles from the Wicomico River, lower input of organic matter from the marshes, and the increasing distance from this source (Cornwell et al. 1994).

Even though in many areas of the Chesapeake Bay aquatic grasses provide important ecological functions: habitat for fish, food supply, enhancement of nutrient accumulation, transformation, and cycling, particle trapping and sediment stabilization (Lubbers et al. 1990, Caffrey and Kemp 1992, Rybicki et al. 1997), the observed coverage of SAV within the Monie Bay component is overall reduced and as a result the benefits this habitat provides are also limited. In Monie Bay the main species of aquatic grasses found is *R. maritima*. This species has a wide salinity tolerance ranging from fresh to near seawater salinity (32 ppt), but grows best between 5 - 15 ppt (Bergstrom et al. 2006). In Monie Creek, *R. maritima* was not found in abundance and thus probably does not represent an important food source for waterfowl or other consumers (Stribling and Cornwell 1997).

A historical review of mapping information for Quadrangle #85 (which includes the Monie Bay component; Figure 4.4.1) from the Virginia Institute of Marine Science (http://web.vims.edu/bio/sav/index.html) has indicated that little SAV has been found within the Monie Bay area since 1978. Instead, most of the SAV that has been recorded for quadrangle #85 corresponds to the area around the Manokin River and associated creeks. Within this area SAV coverage has ranged from 0 – 50 ha, with the highest value recorded for 2002 (Figure 4.4.2). The reasons for this wide variability in the presence of underwater grasses is unknown, but could be due to natural bed dynamics or influenced by environmental conditions including temperature, salinity, light availability, and wave action.

Individual reports on the presence of SAV within Monie Bay include that of Dr. Robert J. Orth, (VIMS; http://web.vims.edu/bio/sav/index.html) on May 25, 1998: SAV was patchy near the mouth of Little Creek; this bed was reported to be denser in previous years. Moving upstream, SAV was expanding around the area where a transplant effort took place, which also seems to be doing very well. Another report includes that of Harold Womack (Salisbury State University) on June 4, 1998: Womack reported a number of beds in 1997, upstream from one of the minor creeks leading into Monie Bay. To check this finding Womack went again in 1998 to check SAV presence at Monie Creek and Little Monie Creek. He found some *R. maritima* in Little Monie, but not much. At Monie Creek, however he saw extensive *R. maritima* beds almost all along its entire length; at some sections SAV was patchy, particularly along the south shore, but at others the beds thickened particularly near the upland line, in some cases almost filling the entire creek. Overall, most of the

R. maritima observed was in good condition and flowering, although some was smaller, presumably immature patches.

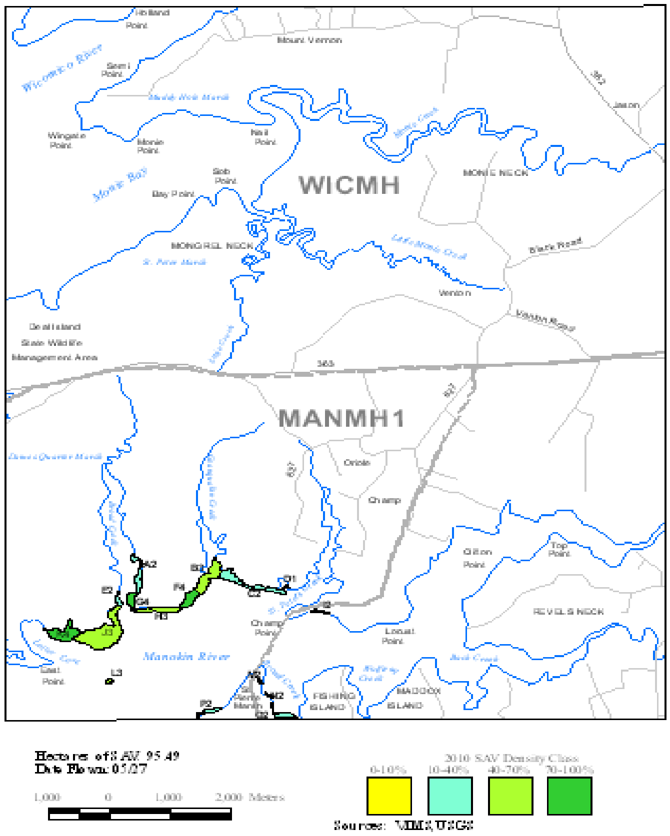


Figure 4.4.1 Area mapped by the Virginia Institute of Marine Sciences (VIMS) around the Monie Bay area (upper part of the map). This area corresponds to the quadrangle #85 for 2010. Source: VIMS (http://web.vims.edu/bio/sav/index.html).

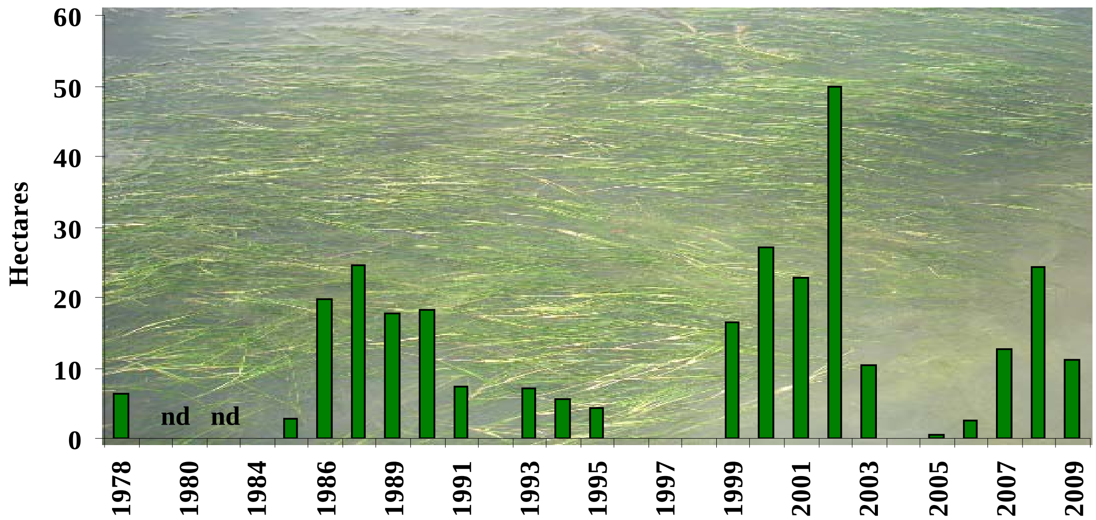


Figure 4.4.2 Longterm distribution (1978-2009) of submerged aquatic vegetation within Quadrangle #85; Figure 4.4.1. This area includes the Monie Bay component. The code "nd" for 1979-1981 indicates that this area was not mapped during that period. Data source: Virginia Institute of Marine Science (http://web.vims.edu/bio/sav/index.html).

Currently, there is not any SAV monitoring in place at the Monie Bay component due to the general absence of SAV there. However, the Reserve's research program initiated an effort south east of Monie Bay at the Deal Island Management Area to monitor the SAV and marsh emergent vegetation communities within the impoundment (Figure 4.4.3). This effort started in 2008 as a request by the Maryland DNR Wildlife Heritage Office to determine the status of SAV and marsh vegetation in this area, which is managed for waterfowl by the State.

Figure 4.4.3 Location of the Impoundment within the Deal Island Management Area.

Preliminary results of this undergoing monitoring effort indicate the presence within the impoundment of one species of underwater grass, *R. maritima*, and one species of macroalgae, muskgrass (*Chara* spp.); both of which are an important food source for waterfowl. Two different ponds (Main Pond and Snag Pond) were monitored within the impoundment and even though both showed variability of SAV cover within the same pond, under the same time frame; each had a very different species dominance pattern. The Main Pond was dominated by *R. maritima*. Snag Pond on the other hand, although still dominated by *R. maritima*, had a significant presence of *Chara* spp. In Main Pond, *Chara* spp. was only reported once in June of 2009, while in Snag Pond *Chara spp.* was always present except on the sampling of September 2008. While there is a decreasing trend of *R. maritima* presence from June to October, *Chara* spp. seems to increase from June to October, suggesting a temporal difference of peak biomass between both species (Figure 4.4.4).

In addition to SAV data, water quality parameters (e.g., dissolved oxygen, temperature, salinity, conductivity, and water depth) are also monitored in these ponds; however, results are not presented here. Data collected is kept by CBNERR-MD and is available upon request.

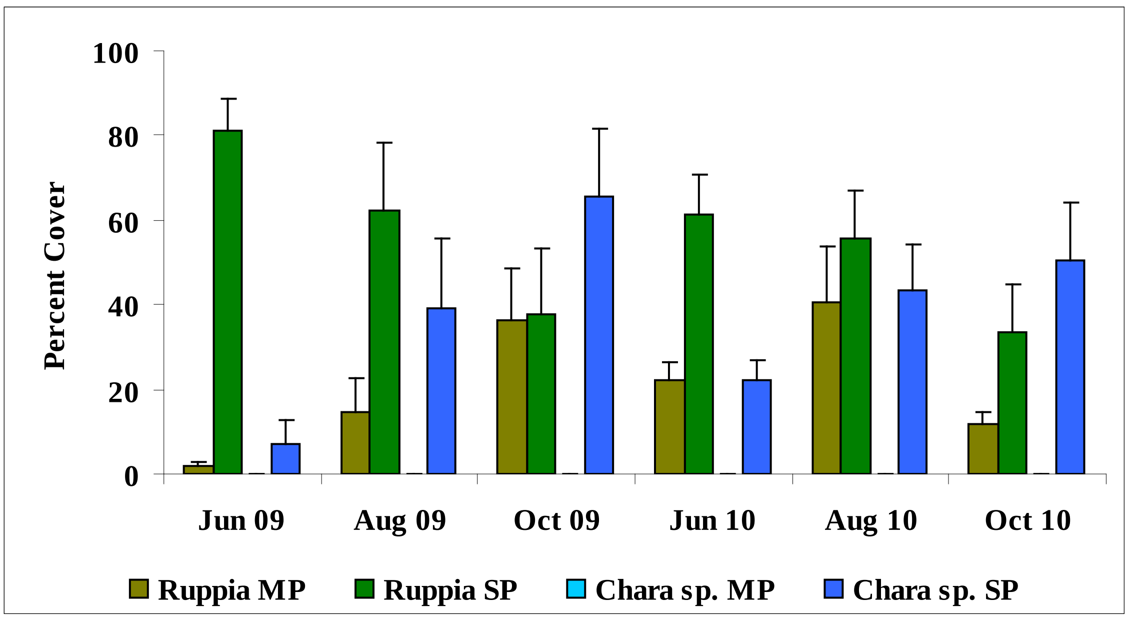


Figure 4.4.4 Percent cover of *Ruppia maritima* and *Chara* spp. at Main Pond (MP) and Snag Pond (SP) within the Deal Island Management Area Impoundment for 2009-2010. Data was also collected on September 2008, but it is not represented in this graph.

4.4.1.2 Elevated streamside bank-marsh

Because of its higher elevation, the marsh in the elevated streamside bank only gets flooded during spring tides. The estimated mean elevation of the bank-marsh is 15.7 cm above the mean elevation of hummocks (or vegetated areas) in the interior marsh (Stribling et al. 2006), which could be a significant difference when related to local site hydrology.

The bank-marsh is generally a quite narrow marsh zone and is dominated by *Spartina cynosuroides* (big cordgrass) and *S. alterniflora*, but other species that could be sparsely found in this zone are *Schoenoplectus robustus* (sturdy bulrush), *Iva frutescens* (Jesuit's bark), *Amaranthus cannabinus* (tidal marsh amaranth), *Symphyotrichum tenuifolium* (saline aster), *J. roemerianus*, *P. australis*, and *S. patens* (CBNERR-MD monitoring observations).

4.4.1.3 Interior marsh

The interior marsh is at a lower elevation than the high and elevated streamside bank-marsh. It receives semidiurnal tidal flooding, which translates into more frequent flooding and for longer periods of time. The sediments are composed of mainly fine-grained silts and clays. This zone is often dominated by *S. alterniflora*, *S. patens*, *S. cynosuroides*, and *A. cannabinus* (Cornwell et al. 1994). The presence and dominance of these species and others in the interior marsh would greatly depend on marsh microtopography and hydrological conditions.

In the interior marshes of Monie Bay, away from tidal creeks, the marsh surface is topographically heterogeneous and it is quite common to find very characteristic hummock/hollow microtopography (Figure 4.4.5). As described by Stribling et al. (2006, 2007), there is a high contrast between hummock and hollow areas. The hummocks are covered with vegetation and are at a significantly higher elevation than the hollows (with a sharp transition to the hollow). The average elevation of hummocks above hollows may range between 7.2 to 12.9 ± 0.8 cm. In contrast, the hollows are at a lower elevation and are devoid of vegetation or plant material both above and belowground; the sediment is soft and unstable.

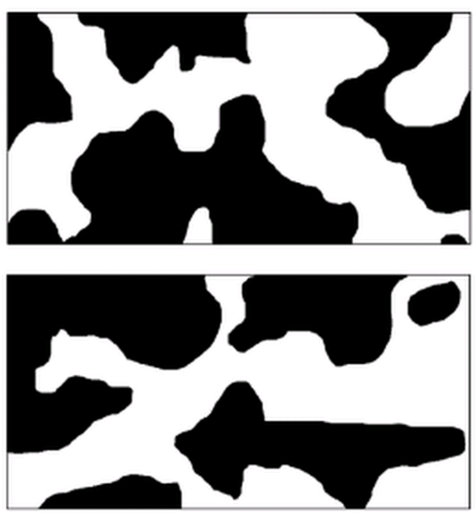


Figure 4.4.5 Digitized image of two 2 m^2 interior-marsh sites (dominated by *Spartina alterniflora*), showing the hummocks in black and the hollows in white. Source: Stribling et al. (2006).

The observed hummock/hollow pattern in the interior marsh seems to reflect the more stressful and variable conditions (particularly flooding) of this zone compared with the bank marsh, which is characterized by a more homogenous plant distribution. The formation of this type of microtopography, however, seems to be controlled by the plants, which by maximizing growth in these areas (hummocks) are able to induce changes (enhancement of soil elevation and oxidation of the sediments with a subsequent decrease in the concentrations of root-zone sulfide and ammonium) in such a way that their sediment biogeochemistry is very similar to that of the higher-elevation homogeneous marsh. This is a typical example of plant-soil feedback that results in a growing environment even though limited to discrete patches (Stribling et al. 2006, 2007).

In an effort to determine if the hummock/hollow microtopography observed in the interior marsh at Monie Bay was or was not an indication of marsh degradation, Stribling et al. (2007) estimated its rate of vertical accretion and age (using ^{210}Pb geochronology) and compared it to that of the bank marsh. Results indicated no significant difference among the vertical accretion of interior hummock (0.50 $\pm$ 0.10 cm yr^{-1}), the bank marsh (0.54 $\pm$ 0.04 cm yr^{-1}), and the interior hollow sediments (0.50 $\pm$ 0.03 cm yr^{-1}). These values are higher than the estimated rate of sea level rise of 0.4 cm yr^{-1} for this region (Stribling et al. 2007; Ward et al. 1988). Considering this information and the fact that the interior marshes are about the same age that the bank marshes, the authors suggest that the spatial variability observed in the Monie Creek interior marsh represents a relatively steady-state microtopography (with no clear progression to uniform plant cover over time), which has persisted for over 10 years (Stribling, personal observation; Stribling et al. 2007).

4.4.1.4 High marsh

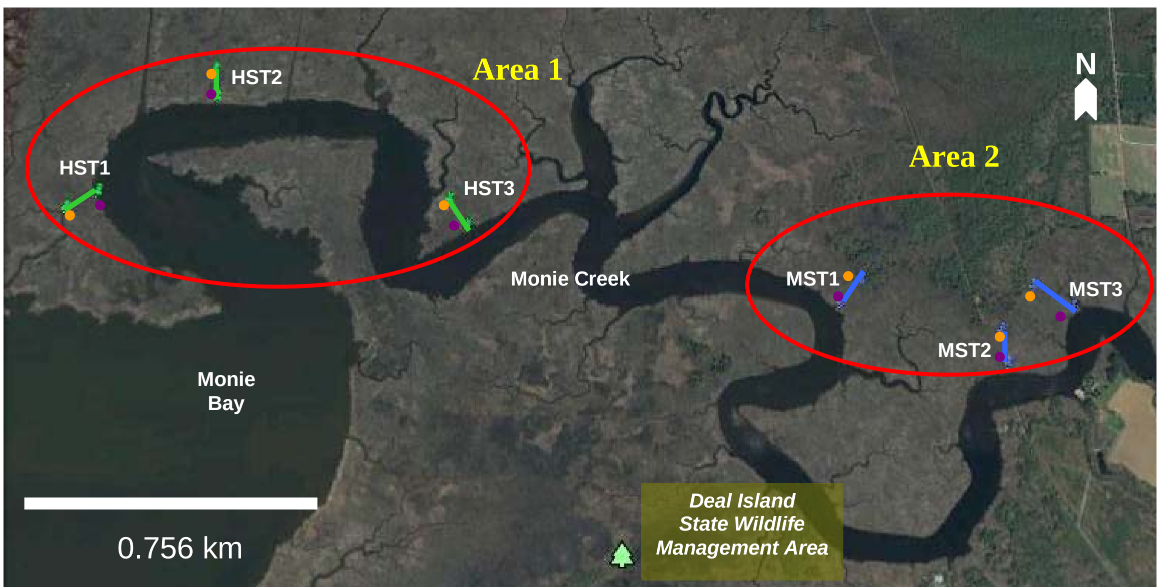
High marsh areas feature the main species *S. patens*, *J. roemerianus*, *D. spicata*, and *P. australis* (Cornwell et al. 1994). It is common to observe in Monie Bay marshes, *J. roemerianus* forming nearly pure patches (of different sizes), sometimes intermixed within stands of *S. alterniflora*, *D. spicata*, and *S. patens*, giving a mosaic pattern appearance to the marsh (Figure 4.4.6).

Figure 4.4.6 Monie Bay marsh showing a patch of *Juncus roemerianus* (dark band) growing among a *Spartina alterniflora* dominated marsh.

Along the less flooded areas of brackish marshes the following species may also be present: *Schoenoplectus americanus* (American bulrush, sometimes forming relatively large patches), *S. robustus*, *Solidago sempervirens* (seaside goldenrod), and *Althaea officinalis* (Common marsh-mallow). The uppermost boundary of brackish marshes, however, is often represented by shrubs mainly *Baccharis halimifolia* (groundsel bush), and *I. frutescens*.

It is in the high marsh where the finest-grained, organic-rich sediments with the lowest bulk densities are deposited. The texture of the soil in this higher areas reflect their location between the higher-energy bay or channel margin sites, being somewhat variable depending on the distance to tidal channels or open water (Ward et al. 1988).

The CBNERR-MD research program started to monitor in 2010 the marsh vegetation of Monie Bay using protocols established for the NERR System (Moore 2009). The long-term goal of this monitoring effort is to characterize this marsh community and determine changes in response to land use and climate change and other environmental factors. For this purpose a total of six transects perpendicular from the shoreline were established in two different areas of the marsh system along Monie Creek. The marsh in Area 1 is closest to the mouth of Monie Creek where the average salinity is 11.80 ± 0.36 ppt (“high salinity – HS”). The marsh of Area 2 is upstream Area 1 and its average salinity is 10.41 ± 0.45 ppt (“medium salinity – MS”; Figure 4.4.7).

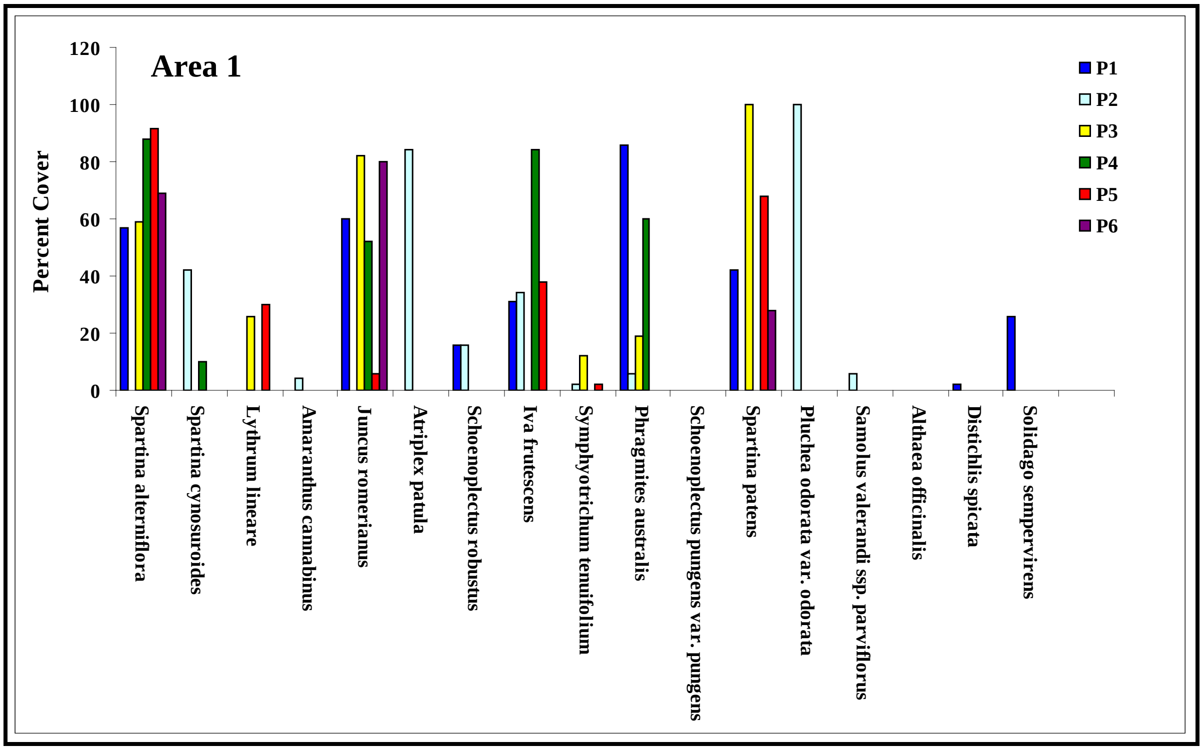


Transect Legend	Area1: High Salinity (HS)	Area2: Medium Salinity (MS)
SET Legend	High Marsh ●	Low Marsh ●

Figure 4.4.7 Map showing the location of six marsh vegetation transects and surface elevation tables (SETs) in Monie Creek, Monie Bay.

Preliminary results of this CBNERR-MD monitoring effort show an overall of 17 species found in the marshes of Monie Creek. From all these species, there is a dominance of *S. alterniflora*, *J.*

roemerianus, *S. patens*, *P. australis*, and *I. frutescens*, but other species are also well represented (Figure 4.4.8). This data also highlights the natural spatial variability within this system, which may be a reflection of the local physical-chemical characteristics of the marsh, particularly regarding hydrology, salinity, and biogeochemistry.



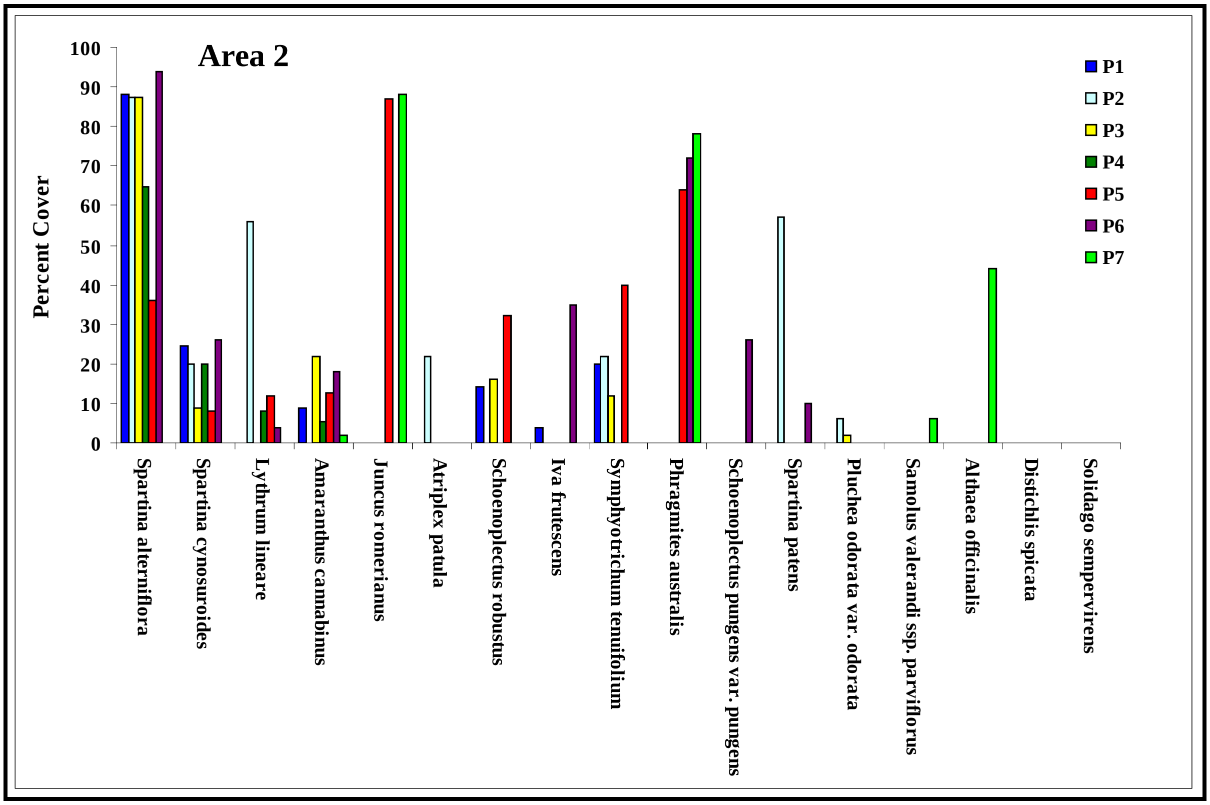


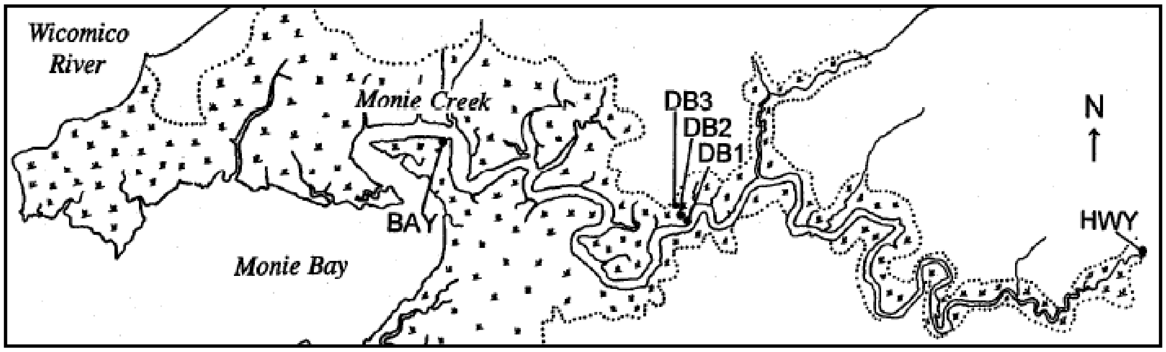
Figure 4.4.8 Species distribution along Monie Creek, Monie Bay. Area 1 and Area 2 are located at different distances from the mouth of Monie Creek (see Figure 4.4.7). Plots P1-P7 are located perpendicular from the margin of the main channel to the interior of the marsh.

4.4.1.5 Marsh ecosystem functioning and biogeochemistry

In contrast to the lack of information on upland ecosystems, the tidal wetland marshes of Monie Bay and the surrounding areas have been relatively well studied during the last two decades. Quantitative samples at some Monie Bay sites indicate that between five to eight plant species dominate the marsh community (Jones et al. 1997, Stribling and Cornwell 1997). Stribling and Cornwell (1997) also indicated that plant biomass is generally dominated by *S. alterniflora*; however, *S. cynosuroides*, *S. patens*, *D. spicata*, *A. cannabinus*, *J. roemerianus*, and *P. australis* are also important in many sites (Table 4.4.3).

Within the Monie Bay system, plant diversity tends to be higher in Little Creek marshes, which are relatively unaffected by agricultural inputs, while plant biomass tends to be greater in Monie Creek marshes, which are heavily affected by farmland runoff (Jones et al. 1997). Similarly, plant tissue nutrient levels tend to be higher in the marshes from the agricultural watershed. Growth of above ground biomass for *S. alterniflora* was significantly increased by experimental nutrient (N and P) fertilization in spring in the marshes of both Little Creek and Monie Creek; however, no responses were evident with fall fertilization (Jones et al. 1997). Pore water profiles of ammonium and phosphate concentrations measured at the same sampling sites shown in Table 4.4.3, show strong seasonal trends that follow plant growth cycles (Figure 4.4.9) and generally higher concentrations in agriculturally influenced marshes (Cornwell et al. 1994, Stribling and Cornwell 2001). Pore water nutrient concentrations are also controlled by plant processes that influence the sediment biogeochemistry at these sites (Stribling et al. 2006).

Table 4.4.3 Biomass (grams dry weight m^{-2}) of marsh plant species found in Monie Creek, tributary of Monie Bay. Sampling stations locations (HWY, DB1, DB2, DB3, and BAY) are shown on the map. C4 and C3 correspond to species that use any of two photosynthetic processes to fix carbon.



Species	HWY	DB1	DB2	DB3	BAY
(C4)					
Spartina alterniflora	358.7	319.9	243.5	0	237.3
Spartina cynosuroides	20.5	271.5	50.3	0	0
Spartina patens	0	0	0	313.2	0
Distichlis spicata	0	0	0	197.7	0
(C3)					
Amaranthus cannabinus	20.4	193.2	140.7	0	0
Juncus roemerianus	0	0	149.2	0	440.0
Ptilimnium capillaceum	91.7	0	0	0	0
Juncus gerardi	64.4	0	0	0	0
Scirpus americanus	0	0	0	38.4	0
Polygonum punctatum	37.2	0	0	0	0
Atriplex patula	0	23.3	0	0	0
Phragmites australis	0	0	26.9	0	107.6

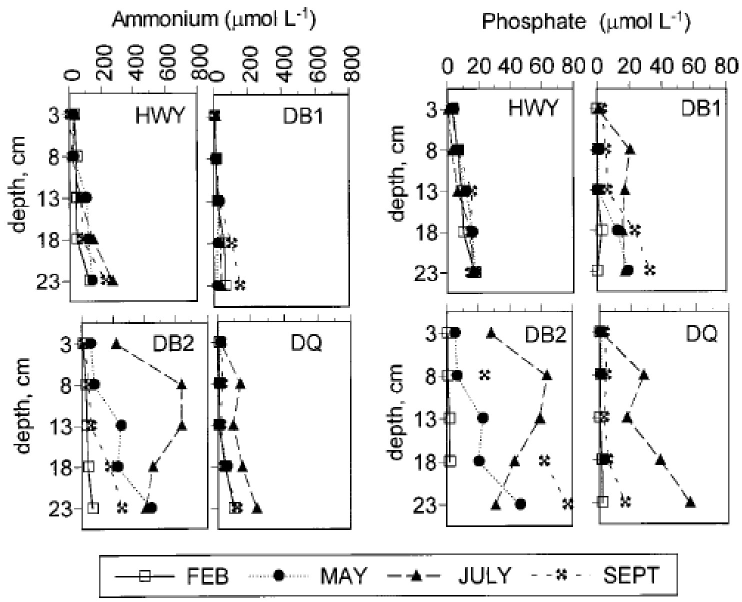


Figure 4.4.9 Vertical profiles of porewater ammonium and phosphate in Monie Creek tidal marsh sediments during the growing season. Stations are as noted in Table 4.4.3, except DQ, which is from the Dames Quarter marsh at the SW edge of Monie Bay. Source: Stribling and Cornwell (2001).

Surveys of stable isotopes of carbon and sulfur suggest that sources of organic matter production in Monie Bay marshes and tidal creeks are relatively balanced, with C4 marsh plants (e.g., *S. alterniflora*), C3 marsh plants (e.g., *J. roemerianus*), phytoplankton and benthic algae all contributing to the organic carbon budget (Stribling and Cornwell 1997). This finding is in contrast to earlier work in higher salinity marshes, where C4 plant production tended to dominate the detrital carbon pools. Furthermore, studies of isotopic signatures of consumer animals in the marsh system, including shrimp, crabs, snails, and fish, suggest that marsh plants make substantial contribution to the diets of these animals (Stribling and Cornwell 1997), in contrast to previous findings in higher salinity systems where algae appeared to be the dominant food source. These are important findings despite the fact that seasonal variations in marsh plant signatures for stable sulfur isotopes may slightly cloud these interpretations (Stribling et al. 1998).

Coupling sediment accretion rates with measurements of nutrient content of accumulating particulate matter suggests that tidal marshes including those at Monie Bay may serve as major sinks for nitrogen and phosphorus burial (Zelenke and Cornwell 1996). Measurements at Monie Bay and Jug Bay CBNERR-MD components suggest that these marshes trap 35% of the nitrogen and 81% of the phosphorus inputs from the surrounding watershed. Burial rates are presented in Table 4.4.4. If these nutrients were not trapped in marsh sediments, they would otherwise be recycled, exported, or buried in the subtidal sediments of the estuary. Relatively high denitrification rates measured in Monie Bay and Jug Bay marsh sediments (approximately 60 μmol N m^{-2} h^{-1}) with high seasonal variability suggests that an additional 10% of the nitrogen may be removed from the estuary via this biogeochemical transformation.

Table 4.4.4 Estimates of burial rates for total nitrogen and phosphorus in tidal marshes of Monie Bay and other tidal and non-tidal sites nation-wide. All studies were based on calculations of burial by measurements of sediment deposition and nutrient concentration. Source: Merrill and Cornwell (2000).

	Tracer	N burial $g\ m^{-2}\ y^{-1}$	P burial $g\ m^{-2}\ y^{-1}$	Author(s)
Salt Marsh				
North Carolina	^{137}Cs	1.3-4.1	-	Craft et al. 1993
Oligohaline/Mesohaline				
Louisiana	^{137}Cs	21	-	DeLaune et al. 1981
North Carolina	^{137}Cs	6.9-10.3	-	Craft et al. 1993
Choptank River, MD	^{210}Pb	19.2-27.1	0.18-1.96	Merrill and Cornwell unpublished
Monie Bay, MD	^{210}Pb	13.6	0.01-1.30	Merrill and Cornwell unpublished
Tidal Freshwater				
Patuxent River, MD	^{210}Pb	23.4	3.54	Merrill and Cornwell unpublished
Otter Point Creek, MD	^{210}Pb	2.74-11.7	0.47-2.09	Merrill and Cornwell unpublished
Tivoli Bays, NY	^{210}Pb	2.37-13.3	0.667-3.06	Merrill unpublished
Nontidal Freshwater				
Wisconsin	^{137}Cs	12.8	2.6	Johnston et al. 1984
Average organic soils	various	14.6	1.46	Johnston 1991
Average inorganic soils	various	1.6	0.26	Johnston 1991
Florida everglades	^{210}Pb	14.1	0.66	Craft and Richardson 1993

Studies of biogeochemical processes have been conducted as part of marsh and estuarine studies in Monie Bay during the last two decades; however, there have been only a few attempts to analyze these data in the context of whole Monie Bay ecosystem.

Various studies of the Monie Bay ecosystem have demonstrated strong ecological effects of differences in nutrient loading associated with land-use in the watersheds of the three Monie Bay's tributary tidal creeks (Jones et al. 1997, Apple et al. 2004, Fertig et al. 2009). Nutrient enrichment effects on the plankton community are related to enrichment of both phytoplankton and marsh autotrophs and the associated enhancement of organic matter lability and nutritional value (Apple 2005). Stable isotopic analyses suggest that marine and brackish water marsh plants, benthic/epiphytic algae, and phytoplankton all contribute to the total ecosystem production of the marsh-tidal creek system and that vascular plants and algae both contributed substantially to the diets of estuarine consumer animal populations (Stribling and Cornwell 1997). Biogeochemical processes in marsh sediments can strongly modify the fate and effects of allochthonous and autochthonous organic matter and associated nutrients and sulfide (Stribling et al. 2001).

A 1990 study conducted at Monie Creek, the major tributary of Monie Bay, showed that marshes in this area go through a temporarily limitation of nitrate and phosphate during the marsh growing season (April to August). This limitation seems to be the result of plant uptake of nutrients (N and P) and denitrification (N; Cornwell et al. 1994). Phosphorus concentrations measured in this area were relatively low, averaging 0.76 ± 0.17 mg g^{-1} in surface sediments and 0.66 ± 0.04 mg g^{-1} in deep sediments (Cornwell et al. 1994). Zelenke et al. (1994) determined that in Monie Bay marshes storage of phosphorus mainly occurs in the form of organic phosphorus, resulting from low particulate inputs and from marsh vegetation such including *S. alterniflora*. Additionally, the authors indicate that phosphorus burial in Monie Bay does not play a significant role in phosphorus retention; preliminary burial estimates of 0.27 g P m^{-2} yr^{-1} are lower than rates (1.0 g P m^{-2} yr^{-1}) measured for subtidal sediments in the Chesapeake Bay.

Overall, sediment biogeochemistry is closely related to the hydrodynamics of the system. For example, the higher energy areas of Monie Bay show lower organic matter concentrations, sediments exposed to continuous flooding are characterized by higher concentrations of reduced sulfur compounds, and those areas under more regular flushed conditions such as bank marshes have higher extractable iron content (Cornwell et al. 1994).

The marshes of the Monie Bay system are sinks for suspended sediments derived from both watershed sources and from marine sources in the lower reaches. Variability in sediment sources, physical disturbance due to storm activity (contributing to erosion and marsh loss under some conditions), and potential flooding increase as a result of sea level rise, make of Monie Bay a system potentially vulnerable to major habitat loss in the future. On the other hand, particulate forms of nitrogen and phosphorus that are part of the total suspended solids load tend to be trapped in marsh sediments creating a major nutrient sink that tends to mitigate eutrophication trends in the estuary (Cornwell et al. 1994). Furthermore, denitrification in marsh sediments represents another sink for nitrogen pollution entering the marsh-estuary complex (Merrill and Cornwell 2000). Although these studies provide an initial analysis of ecosystem level biogeochemical processes, further studies are needed to integrate ecological studies in the watershed, marsh, and estuarine habitats.

A recent dissertation study investigated the factors regulating spatial and temporal variability of bacterioplankton carbon metabolism in the Monie Bay estuarine ecosystem, including comparisons among the three Monie Bay tidal creeks (MC, LMC, LC) and the Monie Bay open bay (Apple et al. 2004, 2006, Apple 2005). Results suggest that differences in land-use and landscape characteristics within Monie Bay drive intra- and inter-creek environmental gradients in salinity, nutrients, and dissolved organic matter (DOM) quality and quantity. This two-year study (2000-2002) also revealed that bacterioplankton metabolism responds positively to system-level nutrient enrichment, and that this response was modulated by freshwater input, which affects the delivery of nutrients and organic carbon to the system. Figure 4.4.10 shows higher total dissolved nitrogen and phosphorus concentrations at the headwaters of LMC than at the open bay, the result of nutrient input from the watershed. This enrichment at the headwaters seems to drive higher bacterioplankton production in this area. In addition, although bacterioplankton responds positively to an increase in nutrient concentrations, temperature is an important factor mediating the magnitude of this response (Figure 4.4.11).

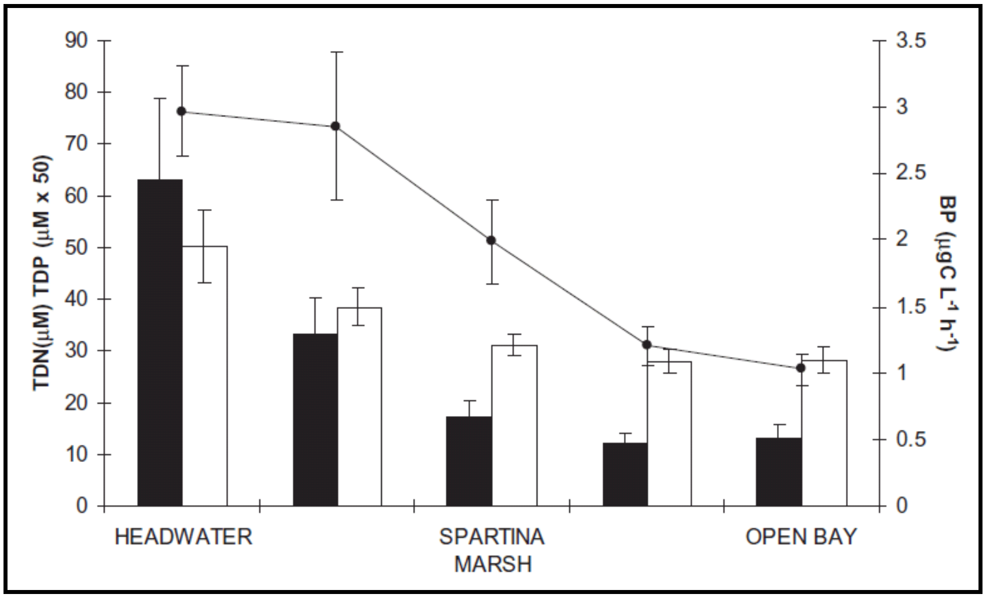


Figure 4.4.10 Axial distributions for annual mean concentrations of total dissolved nitrogen and phosphorus (TDN, TDP, white and black bars, respectively) and bacterioplankton production (BP, line) in the agriculturally-impacted Little Monie Creek. Source: Apple et al. (2004).

Water temperature and organic matter quality exerted an important influence on bacterioplankton carbon metabolism in LMC. Bacterioplankton production (BP), respiration (BR) and total carbon consumption (BCC) all exhibited significant positive temperature dependence (Figure 4.4.11). Different strength of temperature effects on BP and BR resulted in the negative temperature dependence of bacterioplankton growth efficiency (BGE = BP/[BP+BR]). Dissolved organic matter also influenced carbon metabolism, with higher BCC and BGE generally associated with DOM of greater lability. Data analyses suggested that the energy content and lability of DOM may be more important than nutrient content or dissolved nutrients alone in determining the magnitude and variability of BGE. Values of BCC and BGE may be further modulated by the abundance, proportion, and individual metabolism of highly-active cells.

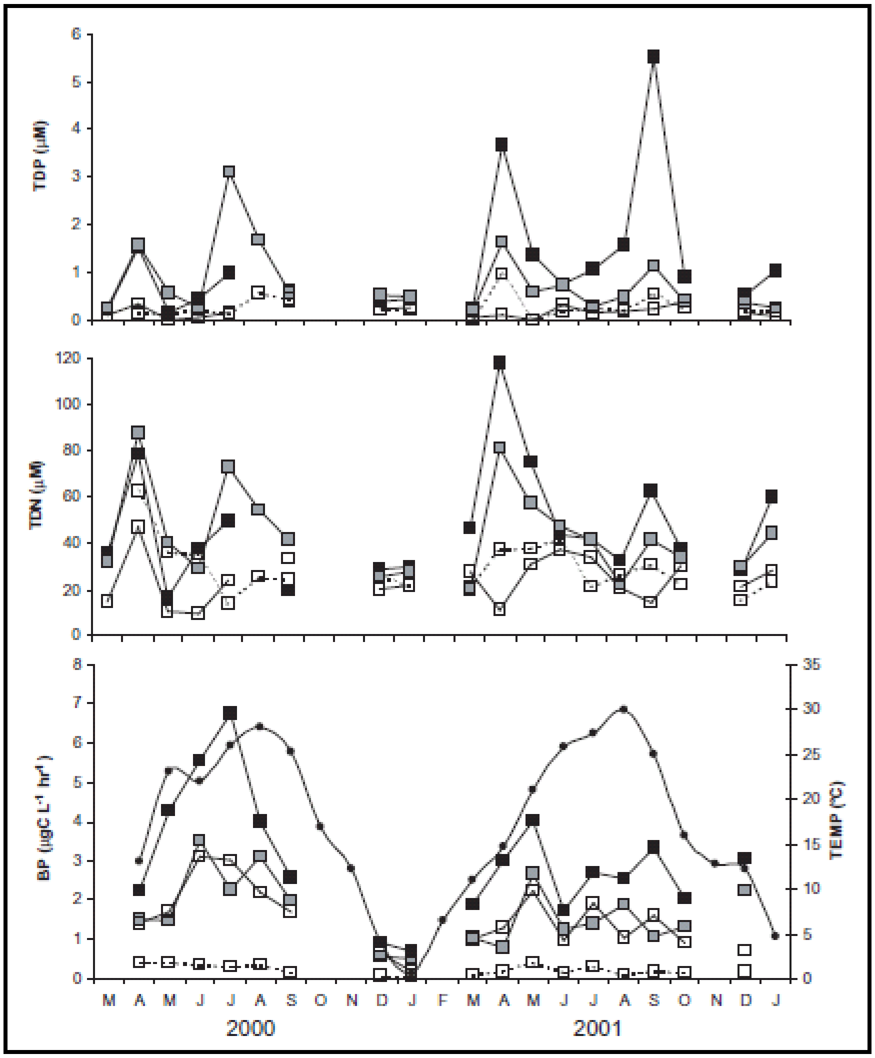


Figure 4.4.11 Mean seasonal variations in total dissolved phosphorus (TDP), total dissolved nitrogen (TDN) and bacterioplankton production (BP) and temperature in Monie Creek (grey squares), Little Monie Creek (black squares), Little Creek (white square, solid line) and open Bay (white squares, dotted line). Source: Apple et al. (2004).

Observed salinity effects on single-cell bacterial activity suggest that other cellular-level properties and phylogenetic composition may also be important factors. In general, the variability of bacterioplankton carbon metabolism in the Monie Bay estuarine system reflects a complex response to a wide range of environmental and biological factors, of which temperature and DOM quality appear to be the most important. Furthermore, this research reveals fundamental differences in both cellular and community-level metabolic processes when freshwater and marine end members of estuaries are compared that may contribute to the variability in bacterioplankton carbon metabolism within and among estuarine systems (Apple 2005).

The rapid response (e.g., hours to days) of the bacterioplankton community to changes in environmental conditions is well suited for tidally-influenced systems where episodic and pulsed nutrient inputs are common. However, the persistence of long-term (e.g., two years), system-specific patterns in bacterial production among the creeks of Monie Bay suggests that the bacterioplankton community also accurately integrate conditions over much longer time periods (e.g., months to years). Thus, the metabolic properties of natural bacterioplankton communities offer a means by which both short-term disturbances and long-term trends can be assessed with one single biological component. Ultimately, this may prove a valuable index of estuarine ecosystem health and function and more accurately define the role of heterotrophic bacterioplankton communities in the coastal eutrophication process (Apple 2004).

4.4.2. Upland Vegetation Community

Upland vegetation within the Monie Bay component consists principally of *Pinus taeda* (loblolly pine), which dominates the canopy, while *Myrica cerifera* (wax myrtle) and *Smilax* sp. (greenbrier) occupy the shrub layer. *Toxicodendron radicans* (poison ivy) covers many of the trees, and grasses dominate the herbaceous zone. These areas are wet and sometimes act as buffers between previously logged areas and marshes at the component boundaries.

Most forests in the watersheds of Monie Bay's tributaries are largely managed as unfertilized tree farms due to economic constraints (Fykes, personal communication). These tree farms, composed of mainly loblolly pine, are abundant in this county, and approximately 60,000 acres are owned by the state and managed privately.

In general, the management of Wildlife Management Areas includes habitat manipulation intended to benefit selected game species and/or to maintain a desired habitat mix. In this context, the Maryland DNR Wildlife and Heritage Service performs tasks such as planting wildlife food plots, creating wildlife openings, establishing nesting cover, and restoring wetlands. These activities may take place in both terrestrial and wetland habitats. In the Reserve's Monie Bay component, active habitat management is limited to food plot establishment/maintenance and maintenance of early successional stages in selected areas, particularly uplands.

4.4.3. Microbiological Components

Bacteria are decomposers, nitrogen fixers in some cases, and pathogens in others. Both aerobic and anaerobic bacteria are found throughout the marsh decomposing organic material accumulated in the soil from plant production. Anaerobic bacteria, found deeper in the marsh substrate, break down the organic matter into ammonium, hydrogen sulfide, methane, and other products. Hydrogen sulfide gives the marsh its characteristic rotten-egg odor. Red streaks in marsh mud also indicate the presence of oxidized iron, a common and important element in the marsh.

Fecal coliforms (*Escherichia coli*) are facultatively-anaerobic bacteria. The presence of fecal coliform (fecal bacteria) in aquatic environments may indicate that the water has been contaminated with the fecal material of human or other animals. Fecal coliform bacteria can enter rivers through direct discharge of waste from agricultural and storm runoff, from mammals and birds, and from human sewage. Considering the dominant land use activities within the Monie Bay watershed, fecal coliform contamination is of concern.

The state of Maryland has a shellfish (oysters and clams) monitoring program which collects information on fecal coliform contamination at different shellfish sampling stations, some located within the Monie Bay system, particularly within what is called the restricted shellfish harvesting area (Figure 4.4.12; MDE 2010). This monitoring effort allows the Maryland Department of the Environment (MDE) to first develop a total maximum daily load (TMDL) for this area, or determine the loading of *E. coli* that this area can receive and still meet water quality standards. Then, if water quality standards for fecal coliform in shellfish are not met, MDE closes the waters to shellfish harvesting to protect human health (MDE 2010).

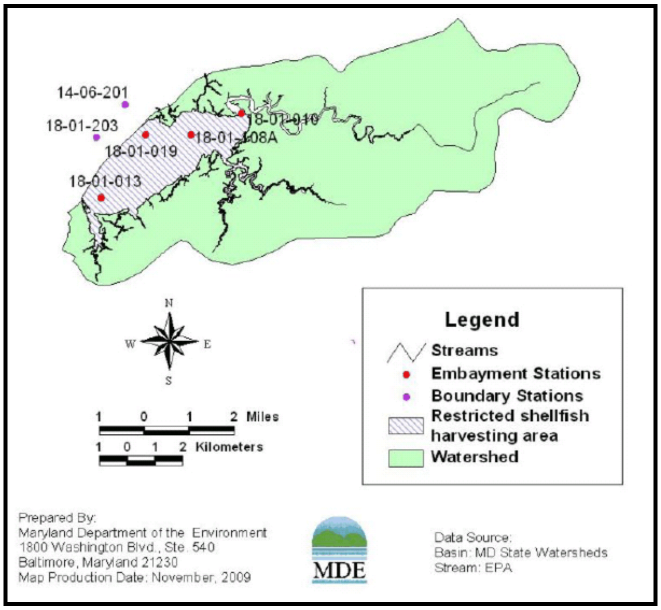


Figure 4.4.12 Shellfish monitoring stations in the restricted shellfish harvesting area in Monie Bay. Source: MDE (2010).

In one of the most recent surveys, all except one of the four monitoring stations in the Monie Bay system had *E. coli* levels that were above the criterion (either the median value or the 90th percentile or both) for closure of shellfish harvest operations (Table 4.4.5). The 90th percentile concentration is the concentration that exceeded the water quality criterion only 10% of the time (MDE 2010).

Table 4.4.5 Bacterial pollution (*E. coli* relative abundance) at shellfish monitoring stations in Monie Bay, based on data from 2004-2009. Source: MDE (2010).

Area	Station	Median		90th Percentile	
		Monitoring Data	Criterion	Monitoring Data	Criterion
		MPN/100ml	MPN/100ml	MPN/100ml	MPN/100ml
Restricted Shellfish Harvesting Area in Monie Bay	18-01-010	43	14	240	49
	18-01-013	5	14	43	49
	18-01-019	9	14	59	49
	18-01-108A	43	14	228	49

With the intent to account for temporal variability, a seasonal analysis of bacterial pollution was conducted; results of this analysis indicated high *E. coli* concentrations (based on the 90th percentile criterion) particularly during the months of December, April, and May; but values were also high in February and September (Figure 4.4.13). These would be the months when the Monie Bay system would be most vulnerable to bacterial contamination (MDE 2010).

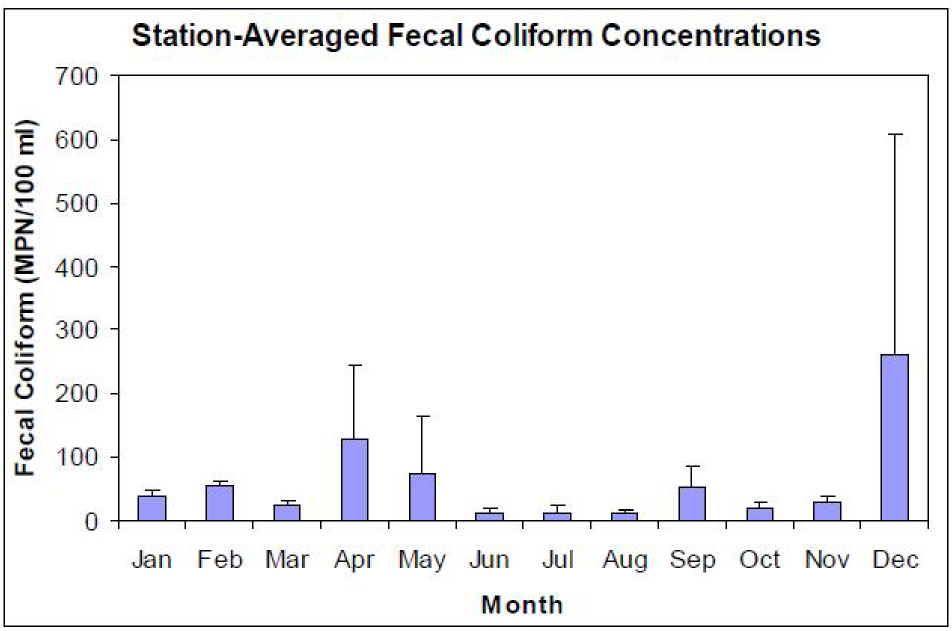


Figure 4.4.13 Seasonality analysis of fecal coliform concentrations at Monie Bay monitoring stations based on data from 2004-2009. Source: MDE (2010).

In an effort to determine the main sources of *E. coli* contamination in Monie Bay, MDE conducted a Bacterial Source Tracking (BST) study, which results indicate that the potential main sources for bacterial contamination in this system are humans and wildlife (28.69% and 28.55%, respectively), followed by livestock (25.50%) and pets (17.26%; MDE 2010).

A summary of various studies that investigated the factors regulating spatial and temporal variability of bacterioplankton carbon metabolism in the Monie Bay estuarine ecosystem was presented in the previous section (4.4.1.5 Marsh ecosystem functioning and biogeochemistry; Apple et al. 2004, 2006, Apple 2005).

4.4.4. Plankton

4.4.4.1. Phytoplankton

Phytoplankton are microscopic, free-floating primary producers in aquatic systems, which serve as a major food source to many organisms, which in turn, are prey to organisms of higher trophic levels. Phytoplankton communities are structured by salinity, temperature, light, and nutrient availability. Algal blooms occur when an excess of nutrients and favorable growth conditions occur in the aquatic system triggering a rapid increase in phytoplankton abundance. Some species if found in high concentrations can become toxic causing serious health issues.

Currently, there are various efforts that have been established to monitor plankton communities. The Phytoplankton Monitoring Network, a NOAA program, began in 2001 to increase public awareness of local waters through volunteer monitoring nationwide (http://www.chbr.noaa.gov/pmn/). However, there are no monitoring stations located in or near the Monie Bay component. The Chesapeake Bay Program also conducts phytoplankton monitoring. This monitoring effort was established in 1984 to obtain more information on phytoplankton spatial and temporal trends within the Chesapeake Bay and its tributaries. Data and information can be accessed at http://www.chesapeakebay.net/data_plankton.aspx. At present, there are no monitoring sites within or near Monie Bay, but there was a temporary nearby station located at North Tangier Sound, Northwest of Haines Point (38 12' 0.443",-76 1' 31.237"; Figure 4.4.14) that was active from 1984 to 1986. Finally, Maryland DNR has compiled phytoplankton monitoring data for Maryland specific sites from 1995 to present day, which can be accessed at http://www.dnr.state.md.us/bay/monitoring/phyto/index.html.

Considering that the North Tangier Sound monitoring station is relatively close to Monie Bay, and it is also a mesohaline environment (salinities ranging between 5-18 ppt), it could be expected that some of the species reported for this station may also be found at Monie Bay. A list of phytoplankton genera and species that were reported for this station between 1984 and 1986 are included in Table 4.4.6. Bacillariophyceae is the most well represented group at North Tangier Sound, followed by dinophyceae. And, an approximate total of 145 different species of phytoplankton representing eight different families were identified (Table 4.4.6).

Studies specifically on phytoplankton presence, abundance, and species composition in the Monie Bay component are lacking. A study conducted by Stribling and Cornwell (1997) on primary producers at Monie Creek using stable isotopes of carbon and sulfur indicated that phytoplankton, in combination with marsh plants and algae, are important primary producers and contribute to the total ecosystem production in this estuarine system.

Chlorophyll *a* has been used for years as an indirect quantitative indicator of the phytoplankton community in a water body. A detailed analysis of chlorophyll *a* data collected at Monie Bay through the CBNERR-MD water quality monitoring, is presented in Section 4.4.6.3 of this site profile.

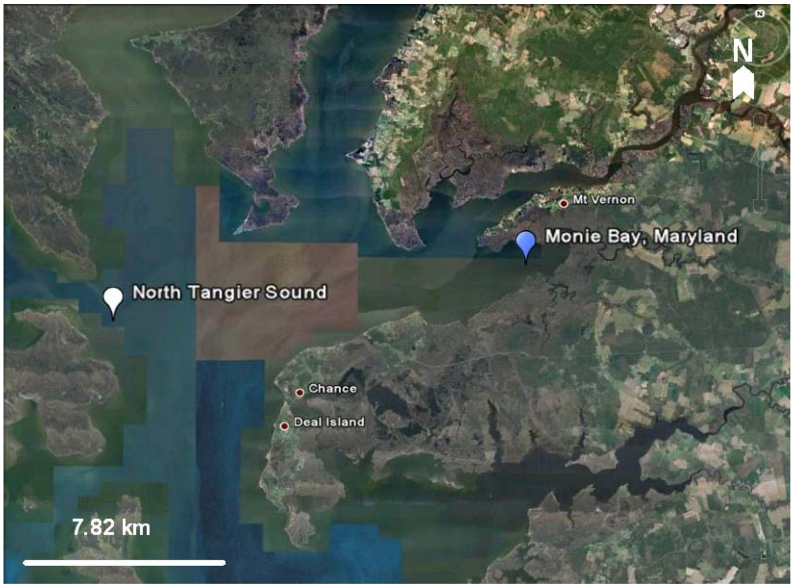


Figure 4.4.14 Location of temporary plankton monitoring station at North Tangier Sound in relation to Monie Bay. This station was in operation between 1984–1986.

Table 4.4.6 List of phytoplankton genera/species observed at the North Tangier Sound temporary plankton monitoring station between 1984 and 1986. Information source: Chesapeake Bay Program (http://www.chesapeakebay.net/data_plankton.aspx).

Bacillariophyceae (Diatoms)		**Chlorophyceae (Green Algae)**	**Dinophyceae (Dinoflagellates)**
Achnanthes	*Licmophora*	*Ankistrodesmus falcatus*	*Amphidinium*
Actinoptychus	*Mastogloia*	*Chlamydomonas*	*Ceratium lineatum*
Amphiprora	*Melosira*	*Chlorella*	*Cladopyxis*
Amphora	*Meridion*	*Crucigenia tetrapedia*	*Diplopsalis*
Asterionella	*Navicula*	*Dictyosphaerium*	*Gonyaulax*
Aulacoseira granulata	*Nitzschia*	*Eutreptia*	*Gymnodinium*
Centrales	*Odontella*	*Eutreptia viridis*	*Gyrodinium*
Ceratulina pelagica	*Paralia sulcata*	*Pediastrum tetras tetraodon*	*Gyrosigma*
Chaetoceros	*Pennales*	*Scenedesmus*	*Heterocapsa triquetra*
Cocconeis	*Plagiogramma*	*Selenastrum*	*Katodinium*
Coscinodiscus	*Pleurosigma*	*Staurastrum*	*Micro-phytoflagellates*
Cyclotella	*Pseudo-nitzschia*	*Tetrastrum heteracanthum*	*Polykrikos*
Cylindrotheca closterium	*Psuedosolenia calcar-avis*	**Chrysophyceae (Golden-Brown Algae)**	*Prorocentrum*
Cymbella	*Rhizosolenia*	*Apedinella radians*	*Protoperidinium*
Dactyliosolen fragilissimus	*Skeletonema costatum*	*Calycomonas*	*Pyrrophycophyta*
Diatoma	*Striatella*	*Dictyocha fibula*	*Scrippsiella trochoidea*
Diploneis	*Surirella fastuosa*	*Ebria tripartita*	**Cryptophyceae**
Ditylum brightwellii	*Synedra*	*Pseudopedinella pyriformis*	*Cryptomonas*
Epithemia	*Terpsinoe*	**Cyanophyceae (Blue-Green Algae)**	**Euglenophyceae (Euglenoids)**
Eunotia	*Thalassionema nitzschioides*	*Agmenellum quadruplicatum*	*Euglena*
Fragillaria construens	*Thalassiosira*	*Anacystis*	**Prasinophyceae**
Gomphonema	*Thalassiothrix*	*Aphanizomenon*	*Pyramimonas*
Grammatophora	*Triceratium*	*Gomphosphaeria*	
Guinardia delicatula	*Tropidoneis lepidoptera*	*Microcystis*	
Leptocylindrus danicus		*Nostocales*	
		Oscillatoria	
		Spirulina subsalsa	

A summary of various studies that investigated the factors regulating spatial and temporal variability of bacterioplankton carbon metabolism in the Monie Bay estuarine ecosystem was presented in the previous section (4.4.1.5 Marsh ecosystem functioning and biogeochemistry; Apple et al. 2004, 2006, Apple 2005).

4.4.4.2. Zooplankton

Zooplankton are a diverse group of aquatic invertebrates, which are typically heterotrophic, sometimes detritivorous. Zooplankton is classified into the protozoa and animalia kingdoms. Free-floating larval stages of commercially important species of oysters, clams, and crabs are also included within the zooplankton community, although they only spend a portion of their life cycle as plankton. Like phytoplankton, zooplankton are a vital part of the food chain, acting as a middle step between their prey (phytoplankton and bacteria) and their predators (species at higher trophic levels, such as fish and their larvae).

The Chesapeake Bay Program and Maryland DNR used to monitor the zooplankton communities within the Chesapeake Bay and tidal tributaries using the same stations as the phytoplankton monitoring sites. Again, there was no monitoring station currently within or near Monie Bay, but the station located at North Tangier Sound described above also collected information on zooplankton from 1984 to 1986. Zooplankton species found at the Tangier Sound monitoring site during the two year period of operation are listed in Table 4.4.7.

Table 4.4.7 List of zooplankton genera/species observed at the North Tangier Sound temporary plankton monitoring station between 1984-1986. Information source: Chesapeake Bay Program (http://www.chesapeakebay.net/data_plankton.aspx).

Protozoan Zooplankton

Class	Order	Family	Genus	Species
Ciliatea		Didiniidae	*Didinium*	
	Oligotrichida	Ptychocylididae	*Favella*	
		Metacylididae	*Metacylis*	
		Tintinnidiidae	*Tintinnidium*	
			Tintinnopsis	*Tintinnopsis dadayi*
				Tintinnopsis dimbriata
				Tintinnopsis fimbriata meunieri
				Tintinnopsis karajacensis
				Tintinnopsis radix
				Tintinnopsis subacuta
	Suctorida	Acinetidae	*Acineta*	
Granuloreticulosea	Foraminiferida			
Lobosa	Arcellinida	Difflugiidae	*Difflugia*	

Animalia Zooplankton

Phylum	Subphylum	Class	Subclass	Order	Family	Species
Annelida		Clitellata	Hirundinea	Rhynochobdellida	Piscicolidae	
		Polychaeta				
Arthropoda	Chelicerata	Arachnida	Acari			
	Crustacea	Branchiopoda	Phyllopoda	Diplostraca	Bosminidae	*Bosmina longirostris*
					Moinidae	*Moina micrura*
					Podonidae	*Pleopsis polyphemoides*
		Malacostraca	Eumalacostraca	Decapoda		
				Isopoda		
				Amphipoda	Oedicerotidae	*Monoculodes* spp.
					Hyperiidae	*Themista compressa*
				Lophogastrida		
		Maxillopoda	Branchiura	Arguloida	Argulidae	*Argulus* spp.
		Maxillopoda	Copepoda	Calanoida	Acartiidae	*Acartia hudsonica*
						Acartia tonsa
					Temoridae	*Eurytemora affinis*
					Centropagidae	*Centropages hamatus*
					Diaptomidae	*Diaptomus*
					Temoridae	*Temora turbinata*
				Cyclopoida	Cyclopidae	*Cyclops vernalis*
						Halicyclops spp.
					Oithonidae	*Oithona colcarva*
				Poecilostomatoida	Ergasilidae	*Ergasilus* spp.
				Harpacticoida		
				Calanoida	Paracalanidae	*Paracalanus crassirostris*
					Pseudodiptomidae	*Pseudodiaptomus coronatus*
				Harpactiocoida	Canuellidae	*Scottolana* spp.
			Thecostraca	Sessilia		
		Ostracoda				
Chaetognatha		Sagittoidea		Aphragmophora	Sagittidae	*Sagitta* spp.
Chordata	Tunicara					
	Vertebrata	Actinopterygii	Neopterygii	Atheriniformes	Atherinopsidae	*Menidia* spp.
Cnidaria		Hydrozoa	Hydroidolina	Anthoathecatae	Hydridae	*Hydra carnea*
Mollusca		Bivalvia				
		Gastropoda				
Nemata						
Platyhelminthes		Turbellaria				
Rotifera		Eurotatoria	Bdelloidea			
			Monogononta	Flosculariaceae	Filliniidae	*Filinia* spp.
				Ploima	Brachionidae	*Keratella cochlearis cochlearis*
						Keratella cochlearis tecta
						Notholca acuminata
					Synchaetidae	*Polyarthra* spp.
						Synchaeta baltica
						Synchaeta bicornis
						Synchaeta stylata
					Trrichocercidae	*Trichocerca similis*

4.4.5. Benthic Macroinvertebrates

The important trophic role of the benthic macroinvertebrate community within an estuarine system is well recognized. Benthic infauna represents an importance source of food for a wide range of organisms within the Chesapeake Bay, some of economic importance, including blue crabs, fish, and birds. Presently not much is known about the benthic macroinvertebrate community of Monie Bay. However, a few studies have provided limited data that lend some insights into the structure of this community.

In an effort to assess the habitat quality of the shallow portions of the Monie Bay estuarine system, Schaffner and Gillett (unpublished 2006) collected sediment cores on August 2004 at two different locations to determine the abundance and composition of the macrobenthic faunal community. Comparative analyses of the benthic community found at muddy low-energy environments of tidal creeks were distinctly different from the community sampled in a nearby sandy, high-energy environment. The muddy site's macrobenthic community was numerically dominated by the tubificid oligochaetes *Peloscolex heterochaetus* and *Tubificoides brownae* and by the aorid amphipod *Leptocheirus plumulosus*. In contrast, over 75% of the biomass of the community was represented by the single tellinid bivalve species, *Macoma balthica*. At the sandy site, the macrobenthic community was numerically dominated by the venerid bivalve *Gemma gemma*, ostracods, and by nemerteans. The largest biomass components of the macrobenthic community in this habitat were the polychaetes *Glycera dibranchiata* and *Marenzelleria viridis*. The tellinid bivalve *M. balthica* was also important at this site.

Birkett (unpublished data) performed a benthic survey at Little Monie Creek and Little Creek in the summer of 1990 using a bottom grab method. His survey was limited, but provided a preliminary list of species present in this area (Table 4.4.8). The bottoms of these creeks were characterized by soft, black mud throughout. According to Dauer et al. (1984) and Tourtellotte and Dauer (1983) the macrobenthic species of the lower Chesapeake Bay can be classified with respect to sediment type. Regions with silty sand sediment ("muddy" as described by Birkett) tend to have less species abundance, but more species diversity than clean sand sediment (Dauer et al. 1984).

In addition, Boesch et al. (1976) indicates that benthic macroinvertebrates of polyhaline mud-bottom communities have high seasonal and long-term variability in the Chesapeake Bay. Also, reproductive seasons and patterns vary between species. Considering that Birkett's study was performed only during one summer, more sampling throughout the year and for several years would be needed to obtain a more comprehensive list of macroinvertebrate species present at Monie Bay and its tributaries.

Dauer et al (1987) concluded that over 90% of macrobenthic species exist within the upper 10cm of the substrate. His study supported the expected pattern of decreasing species presence with increasing depth, which corresponds with a pattern of decreased available oxygen and organic matter also with depth. Conduct studies to analyze the relationships between species presence and abundance and local environmental parameters would be valuable to evaluate habitat condition and to determine which factors are important in controlling population structure of the benthic communities within the Monie Bay estuarine system.

Table 4.4.8 Partial species list of benthic macroinvertebrate fauna collected in Little Monie Creek and Little Creek at Monie Bay. Source: Birkett (unpublished data).

Phylum	Class	Order	Family	Genus/Species	Common Name
Annelida	Polychaeta	Aciculata	Goniadidae	*Glycinde solitaria*	Chevron worm
			Nephtyidae	*Nephtys sp.*	Red lined worm
			Nereididae	*Nereis sp.*	Clam worm
				Platynereis dumerilii	Dumeril's clam worm
Anthropoda	Malacostraca	Amphipoda	Aoridae	*Leptocheirus plumulosus*	Common burrower amphipod
		Decapoda	Palaemonidae	*Palaemonetes sp.*	Common shore shrimp
				Rhithropanopeus harrisii	White fingered mud crab
		Isopoda	Anthuridae	*Cyathura polita*	Slender isopod
Hemichordata	Enteropneusta		Harrimaniidae	*Saccoglossus kowalevskii*	Kowalevsky's acorn worm
Mollusca	Bivalvia	Veneroida	Tellinidae	*Tellina agilis*	Dwarf tellin
				Macoma balthica	Baltic macoma clam
		Myoida	Myidae	*Mya arenaria*	Soft shelled clam

Five of the total number of species collected by Birkett (unpublished data), *Tellina agilis, Macoma balthica, Cyathura polita, Mya arenaria,* and *Glycinde solitaria* are listed as pollution sensitive taxa according to the Chesapeake Bay Benthic Index of Biological Integrity (Llanso 2002). This finding may indicate either that these creeks constitute healthy habitat or that the level of pollution has not reached high enough levels to impact the presence of these sensitive species.

In addition to the study by Birkett, the Maryland Biological Stream Survey (MBSS) program (MBSS) conducted from 2002 to 2006 a survey of benthic macroinvertebrates at Monie Bay tributaries (Monie Creek, Little Monie Creek, and Little Creek) at six tidal and non-tidal sampling sites (Figure 4.4.15). The MBSS is a Maryland DNR Program that conducts since 1993-94 statewide random stream samplings to determine their ecological condition. Some of the organisms that are sampled as part of these surveys include fish, reptiles, and amphibians, and benthic macroinvertebrates; this in addition to water quality and other environmental parameters (more information about this program is found at: http://www.dnr.state.md.us/streams/MBSS.asp). The benthic macroinvertebrate taxa found during the MBSS surveys at Monie Bay are listed in Table 4.4.9.

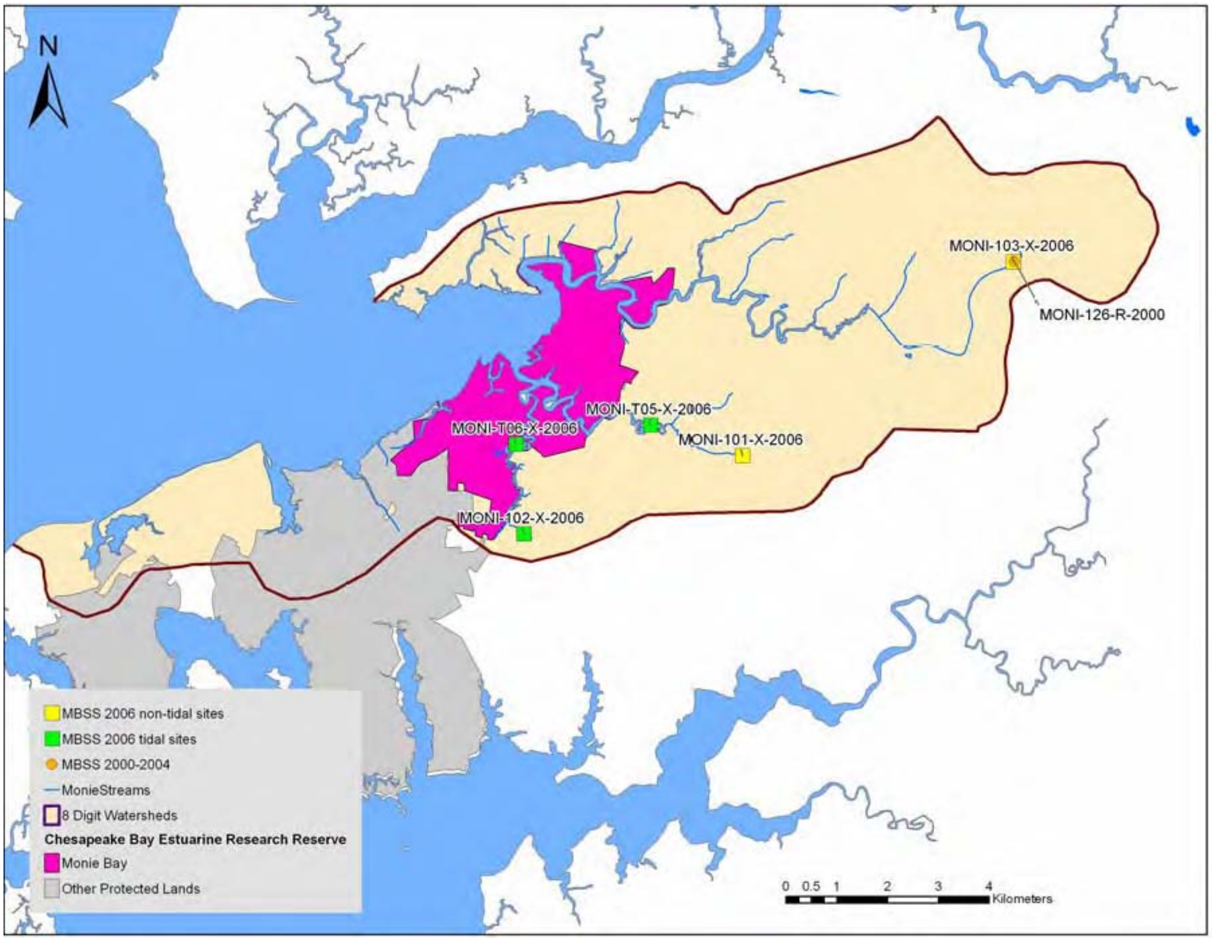


Figure 4.4.15 Location of Maryland Biological Stream Survey sites sampled in tributaries to the Monie Bay component from 2000 to 2006. Source: Stranko et al. (2007).

According to Stranko et al. (2007), the richness of benthic macroinvertebrates at Little Creek and Little Monie Creek sites was low when compared to freshwater non-tidal and tidal areas. The benthic macroinvertebrate community found at these two sites consisted of typical mesohaline taxa including amphipods, isopods, and polychaetes, and one non-biting midge taxa at Little Monie Creek (Table 4.4.8). The tributary to Little Creek had a combination of freshwater (riffle beetles, non-biting midges) and mesohaline (grass shrimp, scuds) taxa, representing a transition area between tidal and non-tidal aquatic environments.

Table 4.4.9 Benthic macroinvertebrate taxa collected during tidal sampling in tributaries to Monie Bay by the Maryland Biological Stream Survey from 2002 to 2006. Source: Stranko et al. (2007).

Class	Order	Family	Genus
Oligochaeta	Haplotaxida	Enchytraeidae	
Polychaeta	Aciculata	Nereididae	*Neanthes*
			Nereis
	Canalipalpata	Spionidae	*Marenzelleria*
Malacostraca	Amphipoda	Corophiidae	*Apocorophium*
		Gammaridae	*Gammarus*
	Decapoda	Palaemonidae	*Palaemonetes*
	Isopoda	Anthuridae	*Cyathura*
		Idoteidae	*Edotia*
Insecta	Coleoptera	Elmidae	*Optioservus*
			Stenelmis
	Diptera	Ceratopogonidae	
		Chironomidae	*Chironomus*
			Dicrotendipes
			Paraphaenocladius

Other common macroinvertebrates found within the Monie Bay system include fiddler (*Uca* spp.) and blue crabs (*Callinectes sapidus*), marsh periwinkles (*Littorina irrorata*), daggerblade grass shrimp (*Palaemonetes pugio*), and eastern oysters (*Crassostrea virginica*).

Although the ecology and populations of crabs have been widely studied throughout the Chesapeake Bay, not much information is available specific for Monie Bay. Birkett (unpublished data), in addition of surveying benthic marcroinvertebrates also briefly surveyed in August 1992 the populations of *C. sapidus* along Little Monie Creek and Little Creek using mark and recapture techniques. Population estimates of adult *C. sapidus* found at these creeks are presented in Table 4.4.10. Actual densities cannot be calculated considering the limited sampling effort of the survey and the fact that the effective range of crab pots (use for capture and recapture) has not been accurately determined.

Table 4.4.10 Estimates of the adult population of *Callinectes sapidus* (blue crabs) at Little Monie Creek and Little Creek, Monie Bay. Estimates were calculated based on the Schnabel method of repeated marking and recapture. Source: Birkett (unpublished data).

Specific Location	**Little Monie Creek**	**Little Creek**
Mouth of creek	139 ± 19	95 ± 11
Middle creek	252 ± 44	70 ± 31
Head creek	74 ± 18	216 ± 8

Historically the Monie Bay area had high commercial finfish and shellfish production (Bundy and Williams 1978); the eastern oyster was a species of economic importance within this area. Rothschild et al. (1994) did an extensive study on the eastern oyster population of the Chesapeake Bay. They suggest that a shell length of 8.5 cm (3.3 in.) is average for a three year old oyster with a maximum life shell length of 15.0 cm (5.9 in.). The oyster is sexually mature at 3.1 cm (1.2 in.), but the fecundity is much lower at this size than that of larger oysters. The authors determined the average mortality rate of disease free oysters to have an instantaneous coefficient of -0.15 yr^{-1} while disease stressed oysters may reach 0.5 yr^{-1}. An increased rate of mortality results in a decrease in both average yield size per recruit and optimal size of first capture (Beverton and Holt 1957).

Oyster harvests in Maryland peaked in 1884 with a harvest of 15 million bushels (Pritchard and Schubel 2001). Oyster abundance is now less than 1% of that of those historic levels (Kemp et al. 2005). Based on yield history, Rothschild et al (1994) concludes that not only oyster abundance but also spawning stock biomass per recruited oyster has declined substantially since the late 1800s. He estimates a 50% decline in oyster habitat in the Maryland portion of the Chesapeake Bay due to mechanical destruction of the bars. The remaining habitat appears to be in poorer quality (MacKenzie 1983, 1989, Seliger and Boggs 1988). Excessive siltation is a specific problem that is destroying the remaining habitat. The population in the late 1800s could filter all the waters of the upper and middle Bay in less than a week, while the current population would require several hundred days to filter the same volume of water (Newell 1988). After a 60-yr period of relative stability, oyster landings began to plummet during the mid-1980s. This protracted decline was associated with several MSX epizootics and the entrenchment of Dermo disease, culminating in record-high oyster mortalities during the drought of 2002 (Tarnowski 2010). As of 2010, oyster populations in Maryland have yet to recover from this disease onslaught.

Local oyster populations have always been very limited in Monie Bay. According to the Yates 1906–1912 oyster bar survey, there was only one small natural oyster bar at the mouth of the bay, adjacent to the Wicomico River channel. However, at one time there were numerous private oyster leases in this area. Monie Bay is currently in MDE restricted waters where shellfish harvesting is prohibited due to public health concerns.

It is interesting to add that from the ecological point of view, Fertig et al. (2007) used oysters, in particular *Crassostrea virginica* (eastern oyster) as a successful biological indicator of nitrogen sources capable of distinguishing between fertilizers and biologically processed wastes. Fertig et al. conducted a study in Monie Bay and its tributaries to determine spatial and temporal patterns of nitrogen sources as influenced by land use. Main findings indicated that probable sources of the high *C. virginica* δ15N values found in Monie Bay proper were the result of sewage/septic wastes coming from the Wicomico River watershed. In contrast, the lowest values were observed at Little Creek, which is the most pristine creek within the Monie Bay system. More information about this study is presented in Section 4.5.2 of this site profile.

4.4.6. Fish, Reptiles, and Amphibians

Over decades of research, estuarine systems like the one at Monie Bay have been shown to play a key role as habitat, nursery grounds, and a food source for many species of animals, including fish, reptiles, and amphibians among others. In Monie Bay, Stribling and Cornwell (1997) showed the importance of marsh plants as a source of organic carbon to aquatic consumers among those various species of fish, mollusks, and crustaceans. Because of the intricate interrelationships between estuarine habitats and associated fauna, the abundance and diversity of species of fish, amphibians, reptiles, and other aquatic organisms within an estuary can help assess its overall ecosystem health.

4.4.6.1 Fish

Fish have been widely studied within the Chesapeake Bay, not only because of their ecological importance but because some species have important economic value in this region, sustaining a significant recreational and commercial fishing industry. Limited information, specific to Monie Bay, is available about this important group. Therefore, there is a need to promote more research and monitoring projects in this area.

Maryland DNR through the MBSS Program (as described in Section 4.4.5) has conducted surveys within the Nanticoke/Wicomico watershed (which includes Somerset County); and separately also conducted surveys in Monie Bay tributaries (see Figure 4.4.15 in Section 4.4.5). Some of the information regarding fish, collected during these surveys, is included below.

MBSS stream surveys conducted within the Nanticoke/Wicomico watershed have estimated an abundance of 1.1 million fish including 28 species in this area, two of which are game species: *Micropterus salmoides* (largemouth bass) and *Esox niger* (chain pickerel). In addition, *Etheostoma vitreum* (glassy darter) and *Acantharchus pomotis* (mud sunfish), also found in the Nanticoke watershed, are two species currently considered at risk of extinction locally (Maryland DNR 2010).

Fish species occurring in the numerous tidal creeks within the Monie Bay component include *Fundulus heteroclitus* (mummichog), *Morone americana* (white perch), *Leisostomus xanthurus* (spot), *Pomotomus saltatrix* (blue fish), and *Brevoortia tyrannus* (menhaden). An extended list of fish species also found in Monie Bay tributaries (Monie Creek, Little Monie Creek, and Little Creek) is included in Table 4.4.11 This list is the result of surveys conducted by the Maryland MBSS from 2000 to 2006 at six tidal and non-tidal sampling sites (Figure 4.4.15; Stranko et al. 2007). Results of this survey show that a total of 19 fish species were captured in creeks around the Monie Bay area. Of those 19 species, 14 species were captured at the three tidal sites, and are almost exclusively estuarine fish species. Only three species were collected at Little Creek, which may be the result of the size of this creek in comparison with the other two (Table 4.4.11). The tidal sites sampled on Little Creek and Little Monie Creek were similar in size, but different in number of fish species.

Table 4.4.11 Fish species recorded in tributaries to Monie Bay by the Maryland Biological Stream Survey Program during 2000-2006. Modified from: Stranko (2007).

		Sampling sites					
		Little Creek		Little Monie Creek		Monie Creek	
Common Name	**Scientific Name**	MONI-102-X-2006°	MONI-T06-2006°	MONI-101-X-2006	MONI-T05-2006°	MONI-103-X-2006	MONI-126-R-2000
American eel	*Anguilla rostrata*			X			X
Atlantic menhaden [E]	*Brevoortia tyrannus*				X		
Atlantic silverside [E]	*Menidia menidia*	X	X		X		
Banded killifish [E]	*Fundulus diaphanus*	X			X		
Banded sunfish *	*Enneacanthus obesus*						X
Bay anchovy [E]	*Anchoa mitchilli*				X		
Common carp [†]	*Cyprinus carpio*				X		
Eastern mosquitofish	*Gambusia affinis*			X			
Eastern mudminnow	*Umbra pygmaea*			X			X
Hogchoker [E]	*Trinectes maculatus*		X				
Mummichog [E]	*Fundulus heteroclitus*	X	X	X	X		
Naked goby [E]	*Gobiosoma bosc*		X		X		
Pumpkinseed	*Lepomis gibbosus*				X		
Redfin pickerel	*Esox americanus*			X			X
Sheepshead minnow [E]	*Cyprinodon variegatus*				X		
Spot [E]	*Leiostomus xanthurus*				X		
Striped bass [g]	*Morone saxatilis*				X		
White catfish *	*Ameiurus catus*				X		
White perch [g]	*Morone americana*		X		X		

° - Tidal Site

* - Species of Greatest Conservation Need

[g]- Gamefish; [†] - Non-native species; [E] - Estuarine

An investigation conducted within the Monie Bay component and two other areas (Hunter et al. 2006) compared the abundance of *Fundulus heteroclites* (killifish), in tidal creeks adjacent to natural marsh stands and near *Phragmites australis* (common reed) stands in initial, early and late stages of invasion. In general, relative fish abundance (catch per unit effort) was highest at the natural marsh sites and declined with stage of *P. australis* invasion from initial to late (Figure 4.4.16).

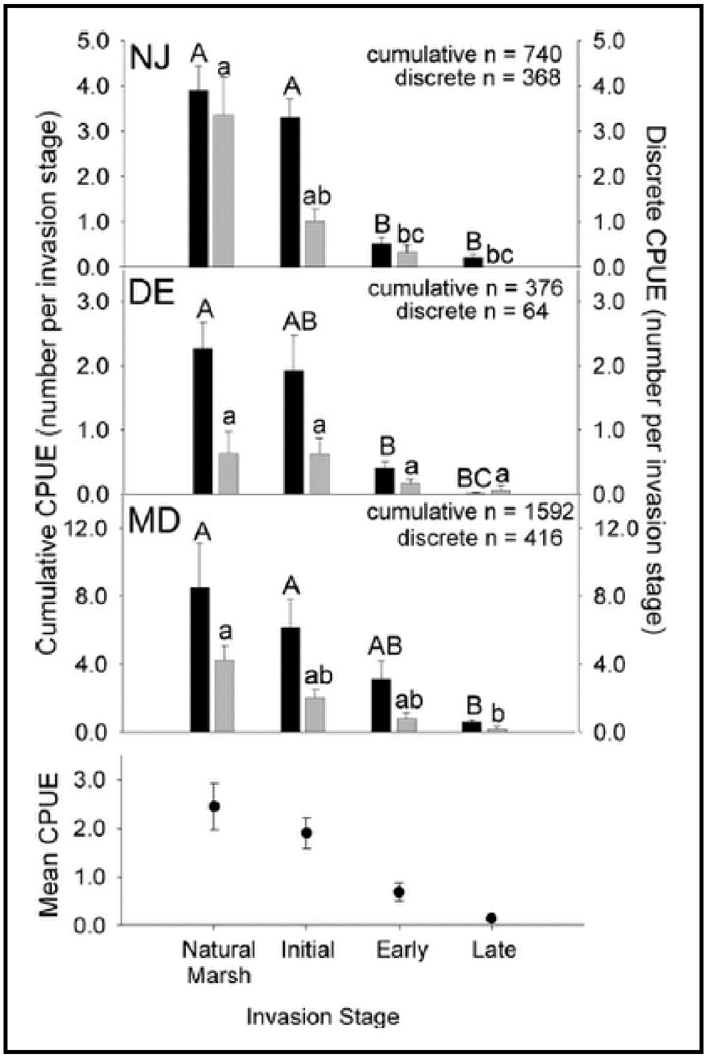


Figure 4.4.16 Comparative study of relative abundances (catch per unit effort – CPUE) of killifish (*Fundulus heteroclites*) in tidal creeks adjacent to tidal marshes with four levels of invasion by the non-native species *Phragmites australis* at Monie Bay and two other sites. Source: Hunter et al. (2006).

Other factors that may affect fish presence and distribution within a particular area are those linked to climatic events that lead to environmental variability. This may play an even more important role as we consider current projections of climate change. In a study conducted by Love et al. (2009) in the coastal lagoons of the lower eastern shore, the authors showed that resident species of fish seem more capable of tolerating environmental variability than seasonally recruited fish (including juveniles), which may be visiting the area for spawning or temporary protection. Changes in stream flow, salinity, and dissolved oxygen as a result of wetter years (in contrast with dryer years), are some of the conditions that may be limiting the presence of certain species of fish within the estuary for certain periods of time. The response of fish populations in Monie Bay as a result of predicted climatic change impacts is an area that needs more research.

In late December 2010, a large fish kill of about two million fish, primarily young of the year (less than one year old) spot and juvenile croakers, occurred in the Chesapeake Bay according to the Maryland Department of the Environment (Figure 4.4.17). The fish kill extended from the Bay Bridge to the Tangier Sound. According to Maryland DNR, water quality data showed temperatures at record lows, at least 4.3 degrees below normal and these juvenile fish are sensitive to cold water. It is believed to be cold stress, not any water quality-related problem that caused this fish kill (Thomson 2011).

Figure 4.4.17 Fish kill in the Chesapeake Bay reported in December 2010. Photo credit: Maryland Department of the Environment.

Contaminants, which may impact fish populations, can reach the estuary via point and non-point source pollution. An example is the presence of endocrine disrupting chemicals (EDC's) such as Estradiol, which has been detected in various Chesapeake Bay tributaries, bays, including Monie Bay. Estradiol interferes with natural hormone levels and can reach the water through sewage treatment plants (from artificial or natural estrogen and waste from animals fed with growth hormones). EDC's and Estradiol are known to negatively affect reproduction in different organisms, including fish (Dorabawila and Gupta 2004). The main sewage treatment plant in Princess Anne is currently implementing nitrogen and biological nutrient removal, and although the effluent from this plant showed the lowest levels of Estradiol compared with other plants along the eastern shore, there is still the concern that even small concentrations may have negative effects on aquatic organisms (Dorabawila and Gupta 2004).

Both recreational and commercial fishing occur in Monie Bay. Monie Creek, for example, is considered a popular area for local sport fishing. Fishermen often fish from the banks or use their private boats. The bank area near Old Drawbridge Road is particularly popular with local residents. Commercial fishing in Monie Bay, on the other hand, includes some net fishing. Fishing for rockfish (striped bass) is particularly popular within the Monie Bay proper. Regarding fisheries management and regulations, these are administered by the Maryland DNR Fisheries Service, while enforcement is conducted by the Maryland DNR Natural Resources

Police. Within the Monie Bay area, controls are applied based on statewide policy and local area interests and needs.

4.4.6.2 Reptiles and amphibians

Reptiles and amphibians are often considered good indicators of ecosystem health due to their close association with aquatic habitats and their sensitivity to different stressors. Evidence exists linking global reptile and amphibian population declines to habitat destruction, and possibly degraded water quality, deforestation, highway construction, and urban development.

Amphibians have not been the focus of much research in Monie Bay. Therefore, any new project or monitoring effort in this area would increase our knowledge and understanding of these groups. One of the few studies that have taken place around the Monie Bay area was through the Maryland DNR Biological Stream Survey (Stranko 2007). As part of this short-term project, some tidal and non-tidal sites within Monie Bay tributaries (Monie Creek, Little Monie Creek, and Little Creek) were sampled for reptiles and amphibians (Figure 4.4.15).

A total of nine reptile and amphibian species have been recorded for the Nanticoke/ Wicomico River basin. In Monie Bay, five species were collected between 2000 and 2006 (Table 4.4.12; Stranko 2007). One of them, the Northern diamondback terrapin (*Mclaclemys t. terrapin*), is considered a species of greatest conservation need. The terrapin is also of significant cultural importance to Maryland, as it is the mascot of the University of Maryland.

Table 4.4.12 Herpetofauna species recorded in tributaries to Monie Bay by the Maryland Biological Stream Survey Program during 2000-2006. Modified from: Stranko (2007).

		Sampling sites					
		Little Creek		Little Monie Creek		Monie Creek	
Scientific Name	**Common Name**	MONI-102-X-2006°	MONI-T06-2006°	MONI-101-X-2006	MONI-T05-2006°	MONI-103-X-2006	MONI-126-R-2000
Lithobates catesbeianus	American bullfrog						X
Lithobates clamitans melanota	Northern green frog			X			X
Lithobates palustris	Pickerel frog			X			
Kinosternon subrubrum	Eastern mud turtle		X				
*Malaclemys t. terrapin**	Northern diamondback terrapin		X		X		

° - Tidal Site

* - Species of greatest conservation need

Even though the survey conducted by Stranko (2007) provides specific information about some species present at Monie Bay, the study was somewhat limited in scope. A more detailed survey of species was conducted for the Blackwater National Wildlife Refuge in Cambridge by the US Fish and Wildlife Service (Table 4.4.13). Considering that this Refuge is in close proximity to the Monie Bay component and that they share some habitat similarities, it could be expected that some of the species of reptiles and amphibians reported for the Refuge may also be found at Monie Bay.

Table 4.4.13 Reptiles and amphibians of Blackwater National Wildlife Refuge. Modified from: USFWS 2008 (www.fws.gov/blackwater).

Scientific Name	Common name
Reptiles	
Agkistrodon contortrix mokasen	Northern copperhead
Chelydra serpentina	Snapping turtle
Chrysemys p. picta	Eastern painted turtle
Clemmys guttata	Spotted turtle
Coluber c. constrictor	Northern black racer
Elaphe obsoleta obsoleta	Black rat snake
Eumeces fasciatus	Five-lined skink
Eumeces laticeps	Broadhead skink
Heterodon platirhinos	Eastern hognose snake
Kinosternon s. subrubrum	Eastern mud turtle
Lampropeltis g. getula	Eastern kingsnake
Mclaclemys t. terrapin	Northern diamback terrapin
Nerodia e. erythrogaster	Redbelly water snake
Nerodia s. sipedon	Northern water snake
Opheodrys aestivus	Rough green snake
Pseudemys rubriventris	Northern redbelly turtle
Sceloporus undulatus hyacinthinus	Northern fence lizard
Scincella lateralis	Ground skink
Sternotherus odoratus	Common musk turtle
Terrapene c. carolina	Eastern box turtle
Thamnophis s. sirtalis	Eastern garter snake
Other reptiles that may occur	
Carphophis a. amoenus	Eastern worm snake
Diadophis p. punctatus	Southern ringneck snake
Elaphe g. guttata	Corn snake
Lampropeltis t. triangulum	Eastern milk snake
Thamnophis s. sauritus	Eastern ribbon snake
Trachemys scripta elegans	Read-eared slider

Amphibians	
Acris crepitans	Northern cricket frog
Acris crepitans	Marbled salamander
Anaxyrus fowleri	Fowler's toad
Hyla chrysoscelis	Cope's gray tree frog
Hyla cinerea	Green tree frog
Hyla versicolor	Gray tree frog
Lithobates catesbeianus	Bull frog
Lithobates palustris	Pickerel frog
Lithobates sphenocephalus utricularius	Southern leopard frog
Notophthalmus v. viridescens	Red-spotted newt
Plethodon cinereus	Redback salamander
Pseudacris crucifer	Northern spring peeper
Pseudacris feriarum	Chorus frog
Scaphiopus holbrookii	Eastern spadefoot
Other amphibians that may occur	
Gastrophryne carolinensis	Eastern narrowmouth toad
Lithobates clamitans melanota	Green frog

4.4.7. Birds and Mammals

4.4.7.1. Birds

The extent and diversity of the wetland communities within the Chesapeake Bay has provided for many years very important habitat for different species of birds. Of particular importance are obligate wetland breeding birds, which depend on these marsh communities for their reproduction and continue success. Some of these species, which we are currently monitoring at Monie Bay, include *Rallus longirostris* (clapper rail), *Rallus limicola* (Virginia rail), *Rallus elegans* (king rail), *Laterallus jamaicensis* (black rail), *Botaurus lentiginosus* (American bittern), *Ixobrychus exilis* (least bittern), *Porzana carolina* (sora rail), *Podilymbus podiceps* (pied-billed grebe), and *Gallinula chloropus* (common moorhen). Unlike other regions in the country, six of the nine North American species in the family Rallidae breed in the Maryland portion of the Chesapeake Bay (American Ornithologist Union 1983).

Even though during the 1950s, most of the Maryland's breeding marsh birds were fairly common in coastal communities (Stewart and Robbins 1958), the loss and degradation of wetland habitat has contributed to the decline of some of these species as indicated by the 1980s findings of the breeding bird atlas project in Maryland (Robbins and Blom 1996).

A more recent study conducted by Tango et al. (1997) provides estimates of breeding populations for Maryland's rails and other obligate wetland breeding birds. This study presents estimates for various regions of the Chesapeake Bay between 1990 and 1992, including Somerset County, where the CBNERR-MD Monie Bay component is located. Results showed *R. limicola* as the most abundant species in Maryland's tidal wetlands (Figure 4.4.18), with the highest numbers found in the large marshes of the lower Eastern Shore (Tango et al. 1997).

Although *R. elegans* was reported as abundant in Somerset County, Patuxent River, and coastal bay marshes for the period 1983-1987 (Blom 1996); this species was not found in any of these sites during the study conducted by Tango et al. (1997). Instead, *R. elegans* was mainly found along the middle of the Choptank River, suggesting a significant change in its distribution and abundance and maybe even a shift in *R. elegans* and *R. longirostris* distribution in Maryland (Tango et al. 1997). In contrast to *R. elegans*, *R. longirostris* were mostly found on the lower Eastern Shore including the Dorchester County marshes (Figure 4.4.19; Tango et al. 1997). According to Stewart and Robbins (1958), this species was common only in the coastal bay marshes, uncommon in Somerset County, and local in the fringe marshes of the lower Chesapeake Bay. Black rails were found in some marshes of Somerset County, but their greatest presence was in the extensive tidal marshes of Dorchester County (Tango et al. 1997).

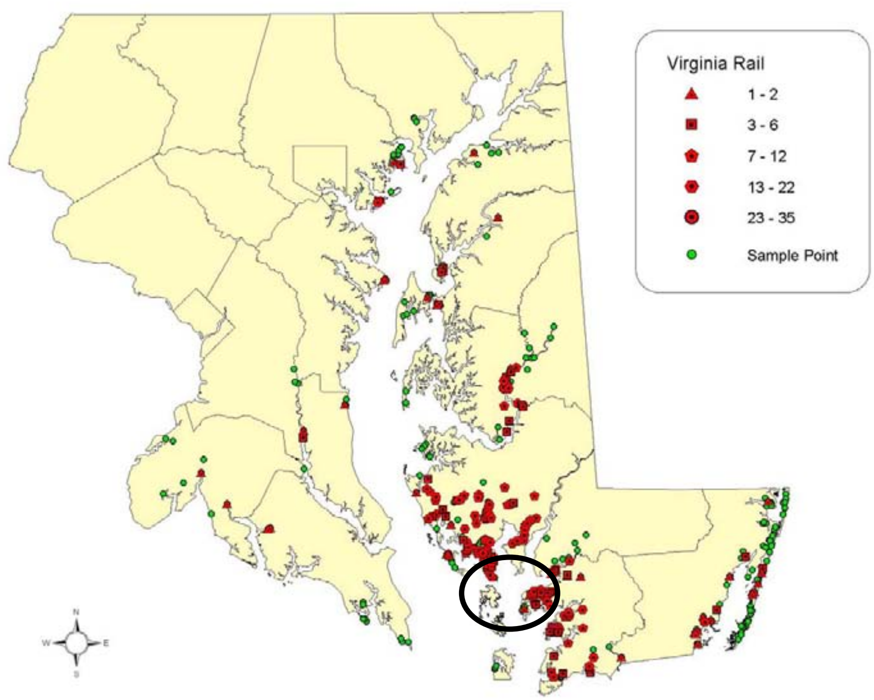


Figure 4.4.18 Distribution and relative abundance of *Rallus limicola* (Virginia rail) during the breeding seasons of 1990 through 1992. Area shown in the circle includes Deal Island Management Area, Monie Bay, and part of the Wicomico River watershed. Source: Tango et al. (1997).

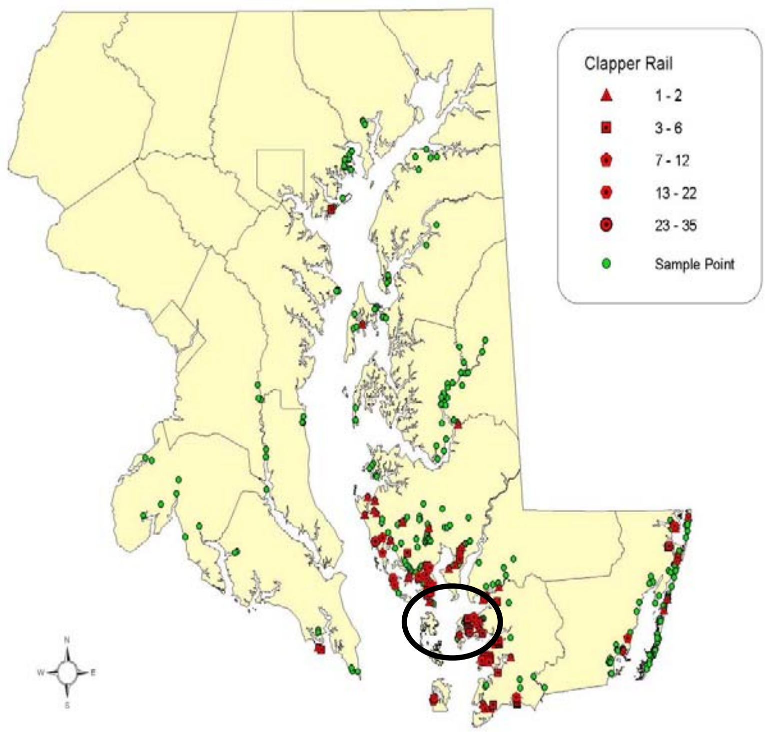


Figure 4.4.19 Distribution and relative abundance of *Rallus longirostris* (clapper rail) during the breeding seasons of 1990 through1992. Area shown in the circle includes Deal Island Management Area, Monie Bay, and part of the Wicomico River watershed. Source: Tango et al. (1997).

In 2008, the CBNERR-MD's research and monitoring program started to monitor obligate wetland breeding birds or secretive marsh birds within the three Reserve components, including Monie Bay, particularly along Monie Creek. The main goal of this project is to document the current status and potential changes of these bird populations as indicators of marsh health (see Section 2.4.7.1 in OPC Site Profile). To do this, a total of eight surveying stations were established in Monie Creek (Figure 4.4.20), and sampled two-three times during these birds' breeding time (between May and July). It is important to note that this is a volunteer-driven program. Preliminary data from this effort at Monie Bay is shown in Table 4.4.14

The four primary species, or secretive marsh birds, expected for this region have been noted. *Rallus longirostris* (clapper rails) are the most abundant, and a total of 124 birds were recorded during these first three years of surveying, followed by *Ixobrychus exilis* (least bittern) with 21 individuals. Numerous other secondary species have also been noted at the different surveying points; the most abundant are listed in Table 4.4.14. *Agelaius phoeniceus* (red-winged blackbird), *Larus artricilla* (laughing gull), *Ammodramus maritimus* (seaside sparrow), and *Cistothorus palustris* (marsh wren) are the most abundant ones. For a more comprehensive list of bird species that have been recorded for the Monie Bay area through this monitoring effort and others, refer to Appendix II.

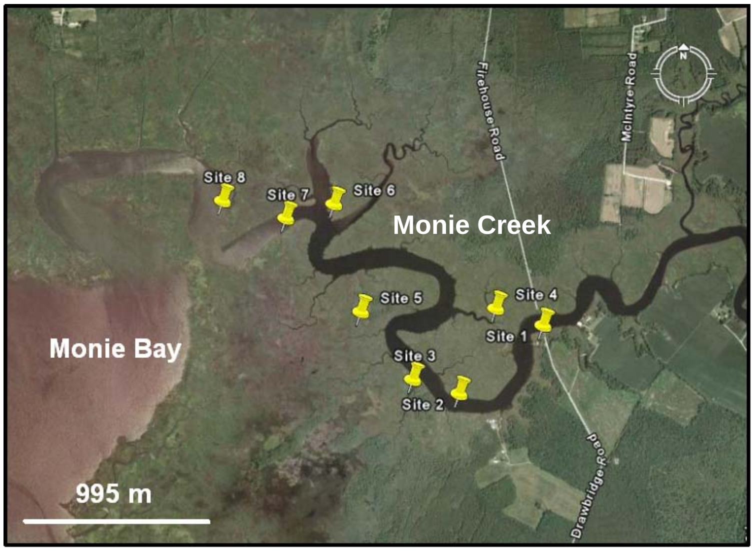


Figure 4.4.20 Location of surveying stations for secretive marsh birds at Monie Creek, tributary of Monie Bay.

Table 4.4.14 Number of individuals of secretive marsh birds and secondary species (the most abundant) recorded at Monie Creek, tributary of Monie Bay from 2008-2010.

Scientific Name	**Common Name**	**Total Number of Individuals Observed**		
		2008	**2009**	**2010**
	Secretive Marsh Birds			
Gallinula chloropus	Common moorhen		1	
Ixobrychus exilis	Least bittern	10	9	2
Rallus limicola	Virginia rail	3	1	1
Rallus longirostris	Clapper rail	23	57	44
	Secondary Species			
Agelaius phoeniceus	Red-winged blackbird		74	146
Larus artricilla	Laughing gull		55	101
Ammodramus maritimus	Seaside sparrow	3	22	66
Cistothorus palustris	Marsh wren	3	20	50
Corvus brachyrhynchos	American crow		16	27

Scientific Name	Common Name	Total Number of Individuals Observed		
Ardea herodias	Great blue heron		9	22
Quiscalus quiscula	Common grackle		1	20
Geothlypis trichas	Common yellowthroat	5	14	20
Zenaida macroura	Mourning dove		21	16
Hirundo rustica	Barn swallow		6	14
Cardinalis cardinalis	Northern cardinal		4	10
Haliaeetus leucocephalus	Bald eagle	1	1	9
Pandion haliaetus	Osprey		2	9
Aix sponsa	Wood duck			8
Progne subis	Purple martin		6	7
Egretta thula	Snowy egret			6
Thryothorus ludovicianus	Carolina wren			4
Tyrannus tyrannus	Eastern kingbird		6	4

Extensive breeding bird surveys in Somerset County indicate a diversity of song birds using the region for habitat (USGS, http://www.pwrc.usgs.gov/bba/).

In the state of Maryland, particularly within the Chesapeake Bay, the recovery of *Haliaeetus leucocephalus* (bald eagle) is a success story. Since this species was first listed as endangered in 1973, its population has recovered significantly and it has been delisted according to the U.S. Fish and Wildlife Service's endangered species list (http://www.fws.gov/endangered/). Annual nesting surveys conducted by the Wildlife and Heritage Service, Maryland DNR, from 1977 through 2004, documented a nearly ten-fold increase in the number of nesting pairs. In 1977, only 44 pairs of nesting bald eagles occurred in Maryland. By 2004, there were 390 documented breeding pairs. It is now estimated that over 500 nesting pairs of bald eagles occur in Maryland annually (http://www.dnr.state.md.us/wildlife/Plants_Wildlife/eagles/mdwleagles.asp).

Results of a 2004 bald eagle nesting survey in Somerset County reveal a relatively abundant population. Out of 30 nests surveyed, a total of 23 were recorded as occupied and active nests. Occupied nests equate to the number of breeding pairs of bald eagles, while active nests are those with evidence that eggs were laid by the breeding pairs (http://www.dnr.state.md.us/wildlife/Plants_Wildlife/eagles/mdwleagles.asp).

The Monie Bay component also supports an abundance of resident and migratory bird populations, including bald eagles (as mentioned above), osprey and numerous hawk species. Waterfowl species include Canada geese, mallards, black ducks and green-winged teals. Birds of interest spotted in the component include *Lophodytes cucullatus* (hooded merganser), *P. carolina*, *B. lentiginosus*, *I. exilis*, and *P. podiceps* (as indicated above), *Circus cyanus* (marsh hawk), *Cistothorus platensis* (sedge wren), *Sterna antillarum* (least tern), and *Gallinula chloropus* (common gallinule).

Waterfowl hunting is an important recreational attraction of the Deal Island Wildlife Management Area (DIWMA, which includes the Monie Bay component). This is one of the few places in Maryland where hunters can find a wide diversity of ducks including wigeons, pintails, gadwalls, green and blue-winged teal, shovelers, black ducks, mallards, scaup, and Canada geese. The DI-WMA's 5,261 ha (13,000 acres) of public property land contains a 1,133 ha (2,800 acres) man-made impoundment which was created over 60 years ago to provide habitat for waterfowl, wading birds, and aquatic mammals. Hunting in part of this impoundment is allowed in accordance with open seasons and all state and federal hunting laws and regulations are applicable. The DIWMA is managed by Maryland DNR, Wildlife and Heritage Service.

4.4.7.2. Mammals

Maryland DNR, through different programs, conducts routine annual surveys of forests, other plants, and wildlife. Surveys for mammals are generally statewide or regional in scale and often data and results are not readily available for examination and analysis. Some results and information from available reports for furbearers, rabbits, and squirrels (Colona et al. 1995, Colona 2005), and deer (Hotton et al. 2005) are presented in this section.

A Maryland statewide bowhunter survey was initiated in 2002 with the main goal of learning more about furbearer and other wildlife population levels across the state (Colona et al. 2005, Colona 2005). These particular surveys were based on harvesting and/or observations by hunters and are analyzed for the entire state and by physiographic province: Appalachian Plateau Province, Ridge and Valley Province, Piedmont Province, Western Coastal Plain Province, and Eastern Coastal Plain Province, where Somerset County is located. Results of species of mammals observed within the Eastern Coastal Plain Province and other provinces are presented in Figure 4.4.21 and 4.4.22.

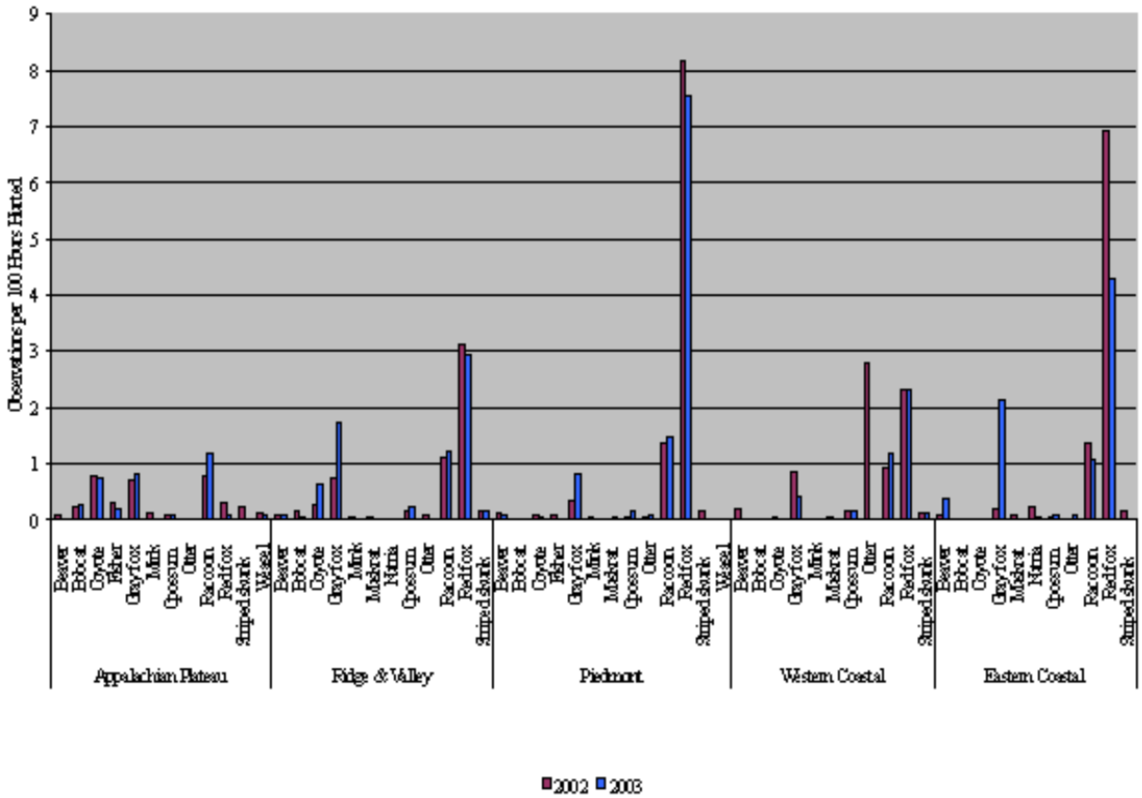


Figure 4.4.21 Regional furbearer observation rates by bowhunters during the 2002-03 and 2003-04 Maryland archery seasons. Information source: Colona (2005).

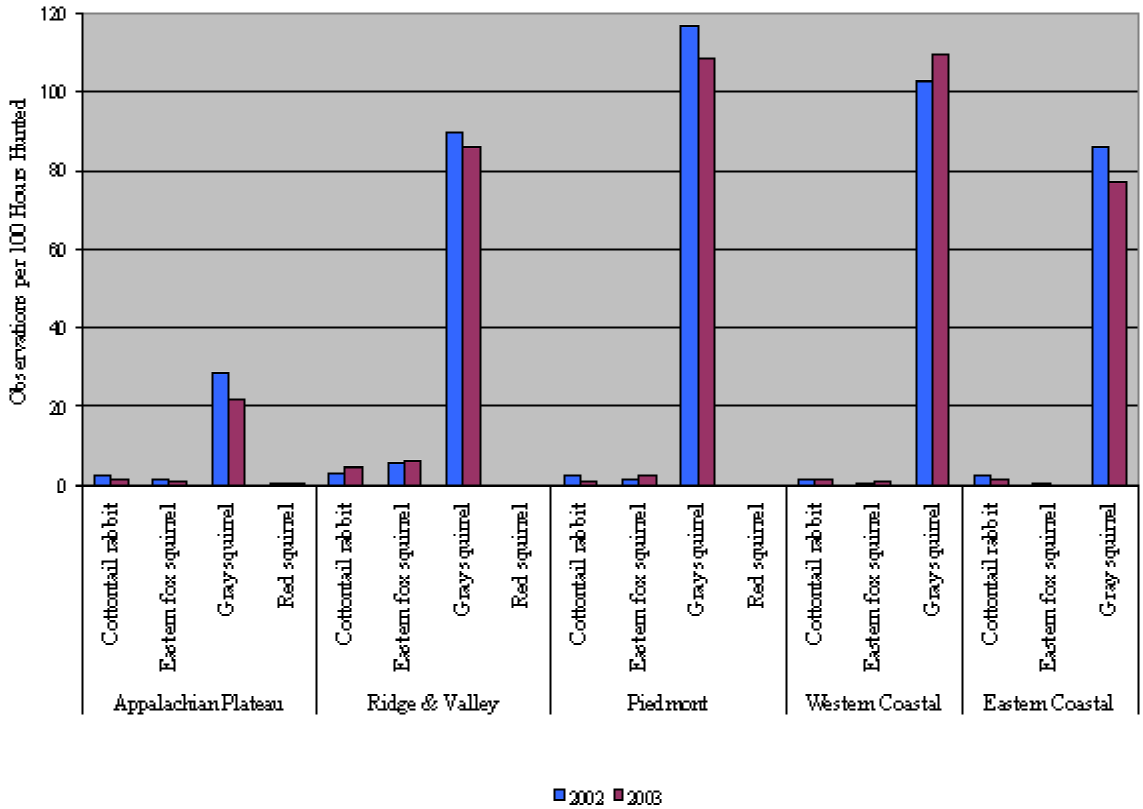


Figure 4.4.22 Regional rabbit and squirrel observation rates by bowhunters during the 2002-03 and 2003-04 Maryland archery seasons. Information source: Colona (2005).

As part of the bowhunter survey initiative mentioned above, the state of Maryland conducts a furbearer, rabbit, and squirrel project. The main goals of this project are to “ensure the viability and ecological integrity of Maryland's native furbearer populations and to promote sustainable and compatible uses of the resource” (Colona 2005). In Maryland the harvesting of the following species is regulated: muskrat, beaver, nutria, long tailed weasel, mink, skunk, otter, fisher, raccoon, opossum, red fox, gray fox, coyote, and bobcat (Colona 2005).

Compared with other counties, Somerset County had relatively high rates of otter harvest, with numbers of 31 and 26 for the 2002-03 and 2003-04 hunting seasons, respectively. Population estimates for other small mammals based on bowhunter surveys were not organized by county, and few clear time trends were evident between surveys conducted in 2002-03 and 2003-04. During the survey of 2002-03, and considering 100 hours of hunting effort, an average of 0.1 coyotes were reported for Somerset County (Colona 2005).

Contrary to otters, deer harvest rates for Somerset County for the 2004-05 hunting season were low when compared with other counties, with a total of 2,716 individuals hunted (using bow, firearms, and muzzleloaders). The number of deer hunted for the different counties ranged between 2,051 in Calvert County to 10,149 in Washington County (Hotton et al. 2005). More information regarding the Maryland DNR deer project can be found in Hotton et al. (2005).

Despite the information that has been collected through these surveys, there has not been much research at Monie Bay focused on mammals, and even a comprehensive list of species present in this area is lacking. On the contrary, there is significant documentation of the mammal species at Blackwater National Wildlife Refuge in Cambridge (Tables 4.4.15). Considering that the Monie Bay system shares some common characteristics with this wildlife refuge and also due to its proximity, it could be expected that some of the species found at Blackwater may also be found in Monie Bay.

Table 4.4.15 Species of mammals reported for Blackwater National Wildlife Refuge. Source: U.S. Fish and Wildlife Service (2008).

Common Name	Scientific Name
Gray squirrel	*Sciurus carolinensis*
Delmarva fox squirrel	*Sciurus niger cinereus*
Southern flying squirrel	*Glaucomys volans*
Rice rat	*Oryzomys palustris*
White-footed mouse	*Peromyscus leucopus*
Meadow vole	*Microtus pennsylvanicus*
Woodland vole	*Pitymys pinetorum*
Muskrat	*Ondatra zibethicus*
Nutria	*Myocastor coypus*
Opossum	*Didelphis virginiana*
Least shrew	*Cryptotis parva*
Masked shrew	*Sorex cinereus*
Short-tailed shrew	*Blarina brevicauda*
Starnose mole	*Condylura cristata*
Eastern mole	*Scalopus aquaticus*
Little brown bat	*Myotis lucifugus*
Big brown bat	*Eptesicus fuscus*
Eastern red bat	*Lasiurus borealis*
Evening bat	*Nycticeius humeralis*
Eastern cottontail rabbit	*Sylvilagus floridanus*
Black rat	*Rattus Rattus*
Norway rat	*Rattus norvegicus*
House mouse	*Mus musculus*
Woodchuck	*Marmota monax*
Red fox	*Vulpes vulpes*
Gray fox	*Urocyon cinereoargenteus*
River otter	*Lutra Canadensis*
Beaver	*Castor canadensis*
Longtail weasel	*Mustela frenata*
Mink	*Mustela vison*
Striped skunk	*Mephitis mephitis*
Raccoon	*Procyon lotor*
White-tailed deer	*Odocoileus viginianus*
Sika deer	*Cervus nippon*

Common Name	Scientific Name
Other Species of Mammals that may Occur	
Northern long-eared bat	*Myotis septentrionalis*
Silver-haired bat	*Asionycteris noctivagans*
Eastern pipistrell	*Perimyotis subflavus*
Hoary bat	*Lasiurus cinereus*
Southern bog lemming	*Synaptomys cooperi*
Meadow jumping mouse	*Zapus hudsonius*
Coyote	*Canis latrans*

One of the only projects conducted at Monie Bay regarding mammals is the nutria (*Myocastor coypus*) eradication program. Unchecked, nutria pose a serious threat to the entire bay ecosystem (Guy, 2007). As a non-native species in Maryland, nutria have negative impacts on marshes because: 1) they have high reproductive capacity, 2) have no natural predators in Maryland and 3) feed primarily on marsh plants, creating open water and removing habitat for native species, especially muskrat and waterfowl. Nutria are now reported in every Maryland Eastern Shore county because of which, Maryland has lost over 73 % of its original wetlands, making the remaining wetlands vital to maintaining the health of the Chesapeake Bay ecosystem, much of which is being degraded by nutria (USFWS 2010). More information about the nutria eradication program and other information regarding this invasive species in Monie Bay is found in Section 4.5.2.4 of this site profile.

4.5. DISTURBANCES AND STRESSORS

The history of the Monie Bay watershed has shown evidence of both natural and anthropogenic disturbance. Natural disturbance has been mainly triggered by climatic events including hurricanes and episodic storm events and biological activity. Anthropogenic disturbances have been mainly the result of direct or indirect human activities (e.g., agriculture, forest clearing, poultry farming, ditching for mosquito control). Sea level rise results from both natural and human causes. The occurrence of disturbances is an important driver shaping the physical environment and as a result the community assemblages found in a particular area. A description of the most prominent natural and anthropogenic disturbances affecting Monie Bay is presented in the following sections.

4.5.1. Natural Disturbances

Hurricanes, storm events, erosion, and biological activity (mainly plant herbivory) are among the most prominent natural disturbances affecting the wetlands of Monie Bay. Two major hurricanes that caused widespread damage within the Chesapeake Bay in 1933 (Stevenson et al. 1988) may have caused some erosion within the Monie Bay area. Other significant storm events that have occurred in this area since 1938 include: Hurricane Hazel, 1954; Connie, 1955; Dianne, 1955; Donna, 1960; Tropical Storm Agnes, 1972. More information about hurricanes, storm, and other climatic events that have affected the Monie Bay area are discussed in Section 4.3.2.2 of this site profile.

A comparative analysis of historical air photographs from 1938 and 1985 was conducted by Ward et al. (1988) to determine long term changes in shorelines, tidal creeks, and interior marsh areas at Monie Bay. Regarding shoreline changes, bank recession or erosion was observed mostly along the land protruding at the junction between the Wicomico River and Monie Bay (positions D, E, F) and at the southern side of Monie Bay (Positions O, P, Q; Figure 4.5.1 and Table 4.5.1). Highest recession rates ranged between 0.5 and 1.3 m yr^{-1}.

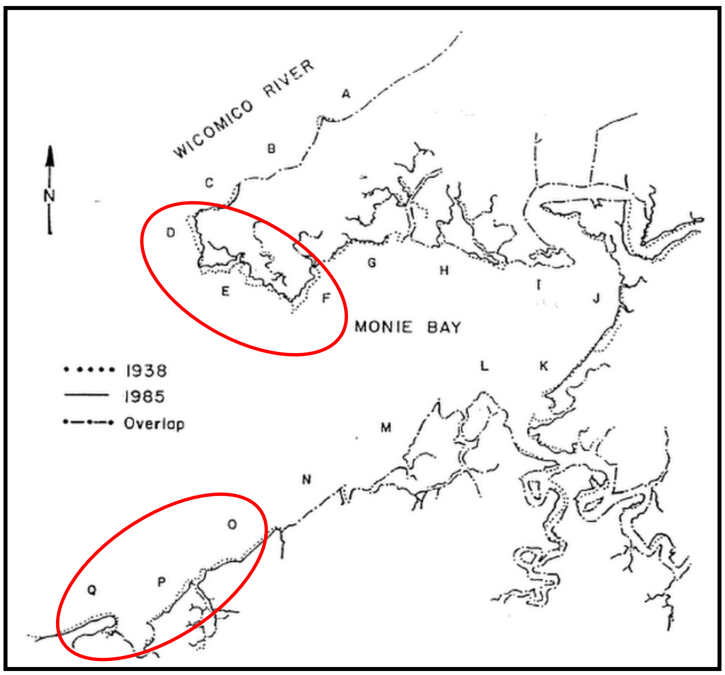


Figure 4.5.1 Shoreline position changes in Monie Bay between 1938 and 1985. Areas with the highest recession rates are highlighted. Map source: Ward et al. (1988).

Table 4.5.1 Shoreline recession/erosion at Monie Bay estimated from aerial photographs from 1938 to 1985. Lines highlighted with light red indicate the areas most affected by bank recession or erosion. Source: Ward et al. (1988).

Location	Erosion (m)	Recession Rate (m yr^{-1})
A	0.0	0.0
B	0.0	0.0
C	15.3	0.3
D	45.9	1.0
E	61.2	1.3
F	61.2	1.3
G	0.0	0.0
H	0.0	0.0
I	0.0	0.0
J	0.0	0.0
K	0.0	0.0
L	23.0	0.5
M	0.0	0.0
N	0.0	0.0
O	30.6	0.6
P	30.6	0.6
Q	23.0	0.5

Biological activity, particularly plant herbivory by the invasive species *Myocastor coypu* (nutria) has shown to be a major problem causing or enhancing marsh degradation in many areas within the Chesapeake Bay. More information about the impacts of nutria on wetlands as well as current population control efforts is presented in the invasive species section of this site profile (Section 4.5.2.4).

4.5.2. Anthropogenic Stressors

Among the most important anthropogenic impacts occurring within the Monie Bay watershed are agricultural activity, including forest clearing, nutrient input to the system which is enhanced by hydrological modifications resulting from road construction, bridges, culverts, and land clearing (Cornwell et al. 1992), aquifer contamination by rural residential septic systems, and ditching for mosquito control. Some of these impacts will be discussed in more detailed in the following sections.

4.5.2.1. Development, land clearing, and nutrient enrichment

Even though Native American populations had cleared land for agriculture around many different regions within the country, particularly in the Mid Atlantic region, the low scale of their activities did not translate to large impacts in the land and surrounding environments. It was not until the time of European settlement and colonization (around 1659) that major erosion and sedimentation in estuarine areas was observed as a result of extensive land clearings. In the

Eastern shore these clearings continued slowly (in comparison with other regions) until the 1700s (Karinen 1958 cited by Ward et al. 1988).

Information regarding the settlement history in Somerset County indicates that initial settlement in this county took place around 1660. Population growth was slow throughout the 1600s and amounted to less than 5,000 people by 1700. By 1730 population doubled and thereafter remained fairly constant until mid-1700s, which was partly attributed to emigration as a result of soil exhaustion. Between 1760 and 1800 population almost doubled again; during the first half of the 1800s, the population did not growth much (Figure 4.5.2; Karinen 1958 cited by Ward et al 1988).

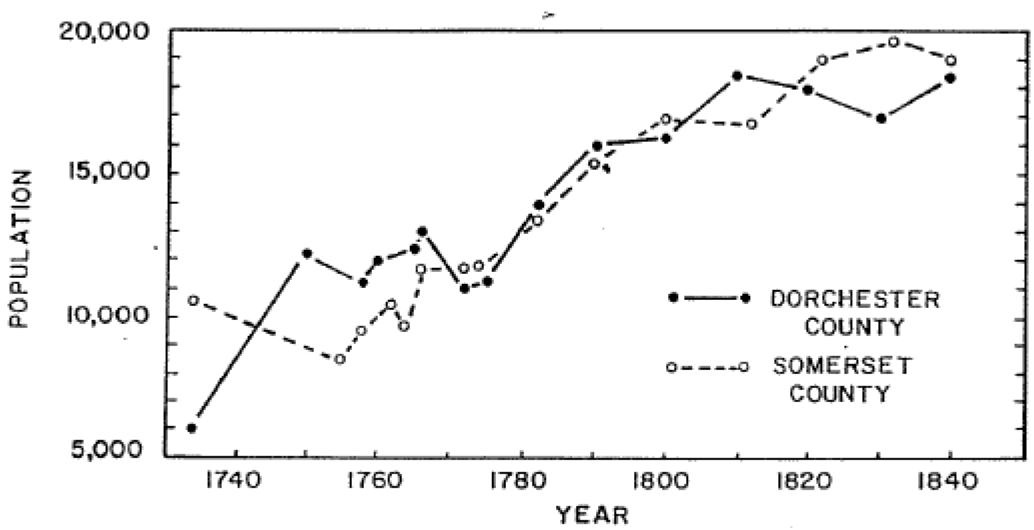


Figure 4.5.2 Population history of Dorchester and Somerset Counties, Maryland. Source: Ward et al. (1988).

Although the rate of land clearance as a result of population growth has been difficult to estimate, it is believed that most of the land clearance took place during the period of the Revolutionary War, specifically around 1790 when the planting of tobacco was changed to the planting of grains, which required more land. After this time, no significant changes in land clearance were observed; therefore, 1790 is considered as the peak phase of early colonial/post-colonial settlement and land clearance in the Somerset/Monie Bay area (Ward et al. 1988).

The major impact that resulted after this massive agricultural land clearance (as described above) was a large scale erosion and transport of sediments to the coastline. These sediments were then deposited in the marshes increasing their vertical accretion. The evidence of this occurrence was revealed when most soil cores analyzed by Ward et al. (1988) showed a sharp rise in their mineral content which coincides with the agricultural horizon during this period as determined from pollen markers. After this, anthropogenic effects on sediment delivery have changed significantly, in some cases to reduce the amount of sediments reaching coastal wetlands (Stevenson et al. 1988).

The smaller settlements within Somerset County include Mount Vernon, Dames Quarter, Deal Island, Chance, and Rumbley which are located on the Bay. Other settlements on the Necks include Oriole, Venton, Manokin and Fairmount, while Route 413 to Crisfield passes through the villages of Kingston, Marion and Hopewell. At the intersection of Routes 13 and 413 in the center of the County is the village of Westover. Somerset County also includes South Marsh Island, Smith Island, and Janes Island in the Chesapeake Bay. Only Smith Island is inhabited, with settlements at Ewell, Rhodes Point and Tylerton (John Pickard Associates, 1991).

In the 1980s State legislation affecting 'Critical Areas' of the Chesapeake Bay shoreline were adopted, and there was a heightened awareness of the environmental impacts of growth and development on such fundamental life-support systems as the aquifers underlying the County (John Pickard Associates, 1991).

At the same time development pressures have continued in bay-front communities. Development pressures have also increased in Route 13 and 413 highway corridors, bringing major increases in traffic. Throughout the 1970's and early 1980's however, Somerset County's overall population declined as anticipated by the 1975 Comprehensive Plan. During the late 1980's the population began to increase, and slow steady growth was anticipated for the 1990's and beyond (John Pickard Associates, 1991). As of the 2009 census estimates the county population was 25,959 people, which has increased slightly from the 1990 census estimates of 23,440 people.

During the early 1990’s, a study conducted by John Pickard Associates (1991) indicated that any new development within Deal Island (in the Dames Quarter to Wenona corridor) had to be very carefully considered in light of the fact that the urbanized area already exceeded Somerset County health standards for septic tanks. Similarly, during this same time, the Somerset County 1990 Comprehensive Water and Sewerage Plan recommended that a central sewage system needed to be constructed in Mount Vernon based on County Health Department findings concerning the high failure rate of septic tanks in the area and the high potential for effluent discharge into the Wicomico River (John Pickard Associates 1991).

The main sources of water in Somerset County are surface water and groundwater. In addition to potential contamination of groundwater through the failure of existing septic tanks, there is concern about aquifer contamination from agriculture and poultry related activities, particularly considering that within this region, agriculture (mainly corn and soybean) and poultry farms are the most prevalent human land use activities. The main influence of agricultural practices on surface and groundwater relates to the application of lime, fertilizer, and manure to crops as ions particularly calcium and magnesium (from lime) and nitrogen and phosphorus (from manure and inorganic fertilizer) may leach into groundwater (Shedlock et al. 1999). Some information regarding groundwater contamination within Somerset County is provided in Section 4.3.4.2 Aquifers and Groundwater and Section 4.3.5.2 Water Use of this site profile.

Information regarding nutrient concentrations and nutrient cycling within the Monie Bay estuarine system as it relates to watershed land use is provided in the following sections of this site profile: 4.3.5 Land and Water Use History, 4.3.6 Water Quality, and 4.4.1.5 Marsh Ecosystem Functioning and Biogeochemistry.

During the early 2000's applications of chicken manure and chemical fertilizers within the Monie Bay watershed were conducted annually before the spring planting and plowed into the soil. Generally one application of chicken manure and/or liquid urea took place in late March to early April, followed by another application of liquid urea in June (Apple et al. 2004). Similarly, the herbicides were applied in the spring between plowing and planting (Brikett, unpublished data). According with Apple et al. (2004) nutrients from agricultural land use enter each creek upstream and are measurably diluted or consumed as they pass downstream into the marsh and are subjected to tidal mixing.

In addition to patterns of nutrient enrichment clearly associated with agricultural practices within the watershed, significant and persistent differences in nutrient concentrations were observed among the creeks during months of little or no fertilizer application (Figure 4.5.3), indicating that acute periodic inputs overlie a more chronic, background level of input from contaminated groundwater and surficial aquifers that have been infiltrated by agriculturally derived nutrients (Speiran et al. 1998, Weil et al. 1990 cited by Apple et al. 2004).

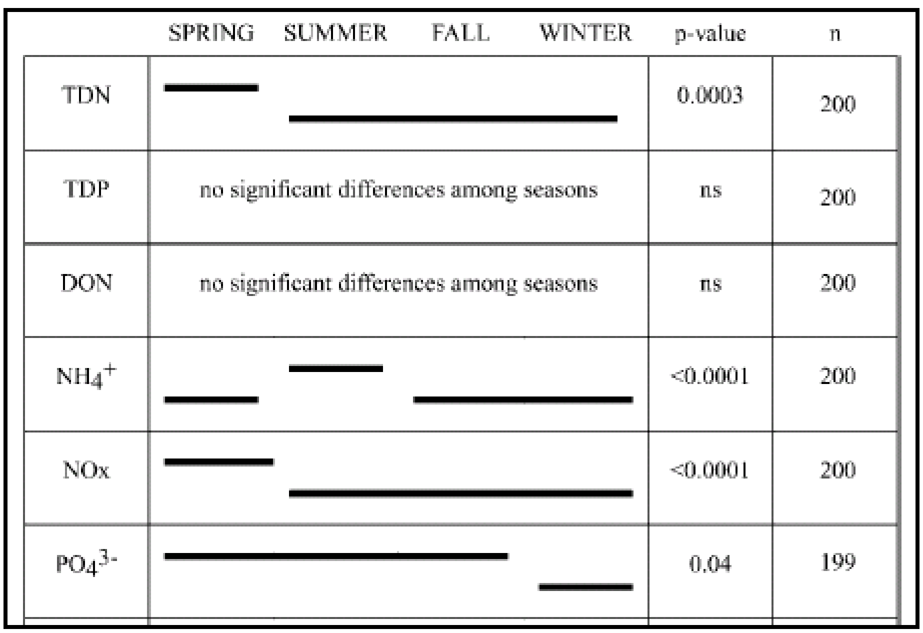


Figure 4.5.3 Comparisons of seasonal means for environmental and biological parameters measured over 2-year sampling period (2000-2002). For each parameter, bar height represents the magnitude of the 2-year mean. Means that are statistically similar share the same bar height. Parameters are defined as follows: TDN = total dissolved nitrogen, TDP = total dissolved phosphorus, DON = dissolved organic nitrogen, NOx = $NO_3^- + NO_2^-$. Source: Apple et al. (2004).

4.5.2.2. Marsh ditching

In the 1930s and early 1940s, coastal wetlands from Maine to Virginia were modified by the construction of grid ditches in order to control mosquito populations (Figures 4.5.4 and 4.5.5; GLARO Ecosystem Initiatives 2010). Ditches were dug in the high marsh linking fresh water pools to their tidal sources, subjecting these areas to daily tide regimes (U.S. Fish and Wildlife

Service 2011). The creation of these ditches altered the natural hydrologic characteristics and biological communities of the salt marsh habitat (GLARO Ecosystem Initiatives 2010, U.S. Fish and Wildlife Service 2011).

Figure 4.5.4 Example of a wetland ditch for controlling mosquito populations in the Chesapeake Bay. Source: Allison Dungan, University of Maryland Center for Environmental Science (http://ian.umces.edu/imagelibrary/displayimage-709.html).

Figure 4.5.5 Aerial photograph of Monie Bay showing the Monie Creek marsh ditches on the right. Source: Ben Fertig, University of Maryland Center for Environmental Science (http://ian.umces.edu/imagelibrary/displayimage-toprated--97-2267.html).

Waterbird surveys conducted at the Deal Island Wildlife Management Area in the early 1980s (Walbeck et al. 1990) revealed that impoundment ponds generally had higher densities of birds than did mosquito control ponds (Table 4.5.2).

Table 4.5.2 Mean densities (birds/ha) of birds on impoundment ponds (n=22) and mosquito control ponds (n=16) in Maryland, 1985. * $P < 0.01$. Source: Walbeck et al. (1990).

Mean densities (birds/ha) of birds on impoundment ponds (N=22) and mosquito control (OMWM) ponds (N=16) in Maryland, 1985.

Species	Pond type: impoundment ($\bar{x} \pm 1$ SE)	Pond type: OMWM ($\bar{x} \pm 1$ SE)
Blue-winged teal (*Anas discors*)	1.8 ± 1.16	0.8 ± 0.41
Ducks other than teal	1.1 ± 0.33	1.0 ± 0.37
American black duck (*Anas rubripes*)	0.8 ± 0.29	0.9 ± 0.36
Total ducks	5.0 ± 1.91	4.3 ± 1.92
Great egret (*Casmerodius albus*)	0.3 ± 0.08	0.1 ± 0.03
Snowy egret (*Egretta thula*)	0.2 ± 0.07	0.1 ± 0.09
Tricolored heron (*Egretta tricolor*)	0.2 ± 0.10	0.1 ± 0.04
Total wading birds*	0.8 ± 0.21	0.3 ± 0.13
Yellowlegs*	0.8 ± 0.16	0.2 ± 0.09
Calidris spp*	0.7 ± 0.38	0.2 ± 0.17
Total shorebirds*	1.6 ± 0.45	0.6 ± 0.26

*p<0.01

(Walbeck et al. 1990)

Currently, the Maryland Coastal Wetland Restoration Partnership is working to restore high marsh habitat on the eastern shore, which in turn will encourage the re-establishment of endemic flora and fauna (Chesapeake Bay Program 2008, GLARO Ecosystem Initiatives 2010, U.S. Fish and Wildlife Service 2011). Water controls structures will be installed to equate marsh elevation enabling the natural formation of permanent and semi-permanent bodies of water (U.S. Fish and Wildlife Service 2011).

4.5.4. Climate change and Sea Level Rise

The impacts of climate change are a growing concern for coastal ecosystems, especially those located in the Chesapeake Bay. The Chesapeake Bay is one of the most vulnerable estuaries in the country regarding the impacts of climate change (Boesch 2008). The Maryland Commission on Climate Change published a Climate Change Action Plan in August of 2009 that describes the future projections and key impacts of climate change. It includes not only the potential effects on the Chesapeake Bay and coastal land, but also future impacts on humans in general.

Sea level rise is due to both natural and human causes. Geologic subsidence due to isostatic rebound and natural climate cycles can both cause sea level rise. In recent years, dramatic increases in greenhouse gas emissions such as carbon dioxide have caused warming ocean temperatures and exacerbated sea level rise. Delaware and Maryland are the third and fourth most vulnerable states to sea level rise (Maryland Commission on Climate Change, 2008).

Somerset County is the second most vulnerable county to sea level rise in Maryland (after Dorchester County). Subsidence, relative sea level rise, and erosion are important processes that may be affecting the Monie Bay Reserve component. Most of this County is less than 40 feet above sea level, with about 90% being less than 20 feet above sea level (MDE 2006). Brackish marshes are becoming wetter due to sea level rise, subsidence, erosion, and herbivore grazing. One example of vegetative community change within Somerset and Dorchester Counties includes loblolly pine islands that are being replaced by more water-tolerant marsh vegetation (Sipple 1999 cited by MDE 2006).

Sea level rise is a serious issue in Somerset County; in some areas wetlands are being lost as a result of this and land subsidence. Maps developed in an effort to predict land changes based on sea level rise have shown that as mean high water increases water will cover large areas of the County. As this occurs uplands may be converted to wetlands; in some areas salt tolerant species are already encroaching into people's yards (Titus and Richman 2001). This also leads to septic system failure (MDE 2006).

Being part of Somerset County estuarine system it is very likely that the Monie Bay component will also be subject to climate change impacts mainly sea level rise. Alterations in salinity, as well as modifications in temperature and precipitation patterns may also be expected, but will not be discussed in detailed in this document.

The star in Figure 4.4.6 indicates the approximate location of Monie Bay on the lower eastern shore of the Chesapeake Bay. The lower eastern shore of the Chesapeake Bay, specifically Somerset, Wicomico, and Dorchester Counties have lower sea levels compared to the western shore (Figure 4.5.6). The locations in red indicate land that is approximately 1.5 meters below sea level and would likely be underwater at high tide if sea level where to rise 50 cm or more (Johnson 2000, Titus 1998). The Monie Bay component of the Reserve is located within the vulnerable zone sitting less than 1.5 meters above sea level. If sea level continues to rise, the reserve could be underwater resulting in dramatic changes on flora and fauna.

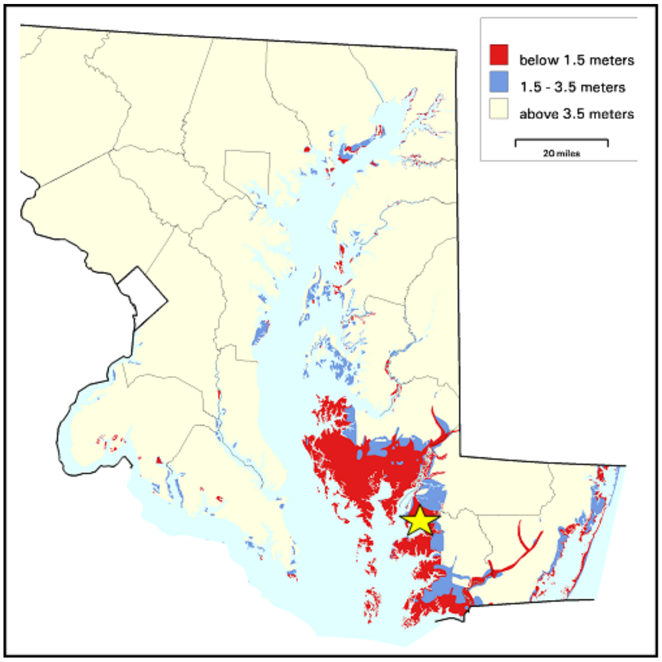


Figure 4.5.6 Location of coastal land in relation to sea level, the star indicates the location of the CBNERR-MD Monie Bay component on the lower eastern shore of the Chesapeake Bay. Source: Titus (1998) and Johnson (2000).

According to the NOAA tide gage station in Cambridge Maryland, approximately 60 miles from the reserve, sea level is rising at 3.48 ± 0.39 mm yr^{-1} (0.14 ± 0.02 in. yr^{-1}; Figure 4.5.7). Values were calculated for the period of 1943 through 2006; therefore, it translates to a change of 35 cm (1.14 feet) in 100 years (CO-OPS 2008). If the projections are correct, sea level will be over halfway to the 50 cm (20 in.) mark of complete inundation of the reserves ecosystem.

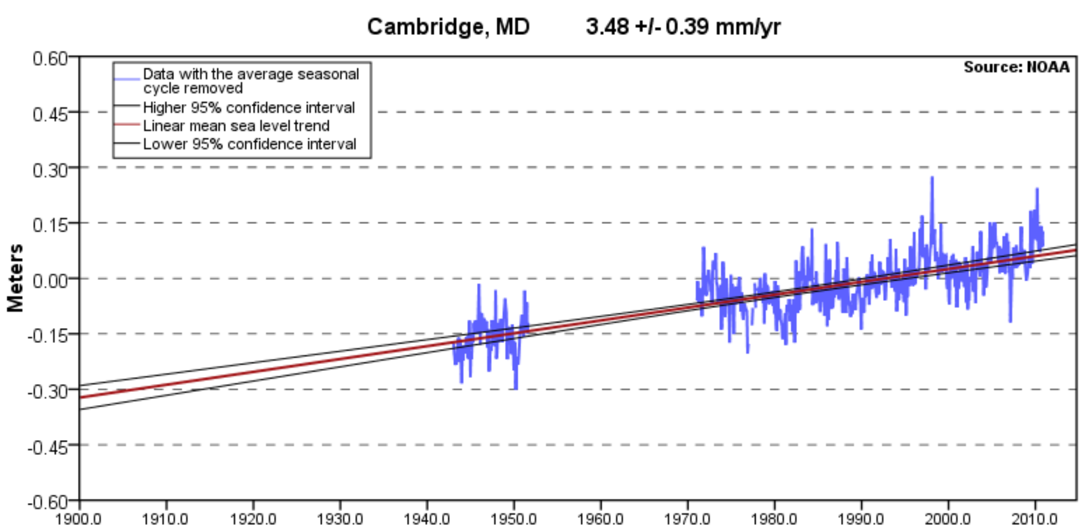


Figure 4.5.7 Mean sea level rise for the period of 1943 through 2006 at a NOAA tide gage station located in Cambridge, MD. Source: CO-OPS, NOAA (2008).

Because of limited sources of inorganic sediments from the watershed that contribute to vertical accretion, salt marshes overall are more vulnerable to sea level rise compared to freshwater marshes. Salt marshes of the Chesapeake Bay are highly susceptible as current conditions indicate that sufficient organic matter and inorganic sediment is not being received to keep up with projected sea level rise (Najjar et al. 2000). Furthermore, groundwater withdrawal from underground aquifers is also contributing to land subsidence and the inability to combat sea level rise in the Chesapeake Bay (Stevenson et al 1999).

The sediment accretion rate of Monie Bay marshes ranges between 0.15 and 0.63 cm yr^{-1} (0.06 and 0.25 in. yr^{-1}) while the average sea level rise for the region is approximately 0.30 to 0.40 cm yr^{-1} (0.12 to 0.16 in. yr^{-1}; Ward 1988, 1998). Based on this information, it could be said that the majority of the marshes of Monie Bay are currently keeping pace with sea level rise; however, there are several locations suffering from increased inundation and have transformed into mud flats (Cornwell et al. 1994). For more information regarding vertical accretion rates and sedimentary processes at Monie Bay marshes, refer to Section 4.3.3.2 Vertical Accretion.

In an effort to monitor the impacts and response of the Monie Bay estuarine system to climate change related impacts (particularly sea level rise), the CBNERR-MD research program established in 2010 a total of six marsh emergent vegetation transects and twelve surface elevation tables (SETs; technology used to measure marsh surface elevation) at Monie Creek (see Figure 4.4.8 for location of marsh transects and SETs).

The first survey of these marsh vegetation transects at Monie Creek, has shown *S. alterniflora*, *J. roemerianus*, *S. patens*, *P. australis*, and *I. frutescens* as dominant species. Depending on these species (and less dominant species) tolerance to increased flooding, sea level rise may lead to changes on their distribution and abundance, with a probable shift to more suitable habitat. This transition, however, is highly dependent on the availability of space. Horizontal inland migration is inhibited by human and constructed barriers such as development, bulkheads, and seawalls (Najjar et al. 2000). The tall form of *S. alterniflora* often dominates the marsh edge while, the short form of *S. alterniflora* and *J. roemerianus* dominate mid to higher marsh locations (Tiner 1987). Considering that the tall form of *S. alterniflora* is a highly tolerant species to inundation and salinity, it would make it a great competitor under sea level rise predictions and it would probably out-compete less tolerant species like *J. roemerianus*. One prime example of species changes on the eastern shore is the transition from Loblolly Pines to more flood tolerant species (Sipple 1999).

As part of the Maryland's Climate Change Action Plan, Maryland DNR (under the Climate Action Team) is leading among others an effort to use the Sea Level Affecting Marshes Model (SLAMM) to identify transitional wetland movement from their initial state to a 2100 year projection for wetlands within the Chesapeake Bay. This is being done with the main purpose of better inform State's land acquisition for protection (Papiez C. - Chesapeake and Coastal Program, Maryland DNR, personal communication). A draft of this model results for the Monie Bay area are presented in Figure 4.5.8. The shaded green area indicates a 100-year projection of those lands where wetlands may migrate in the face of sea level rise.

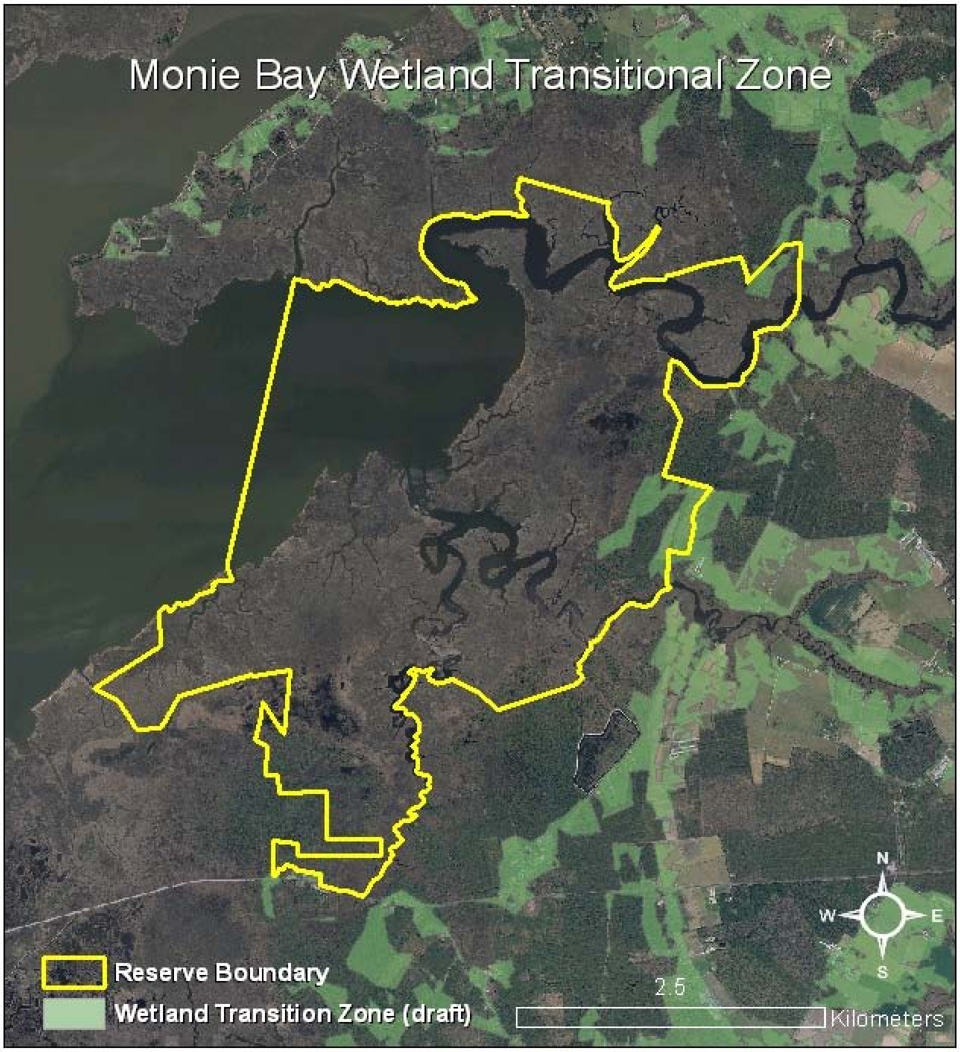


Figure 4.5.8 Wetland transitional zone estimated from the Sea Level Affecting Marshes Model (SLAMM) for the Monie Bay area. Draft map courtesy of Chelsie Papiez, Chesapeake and Coastal Program, Maryland DNR (2011).

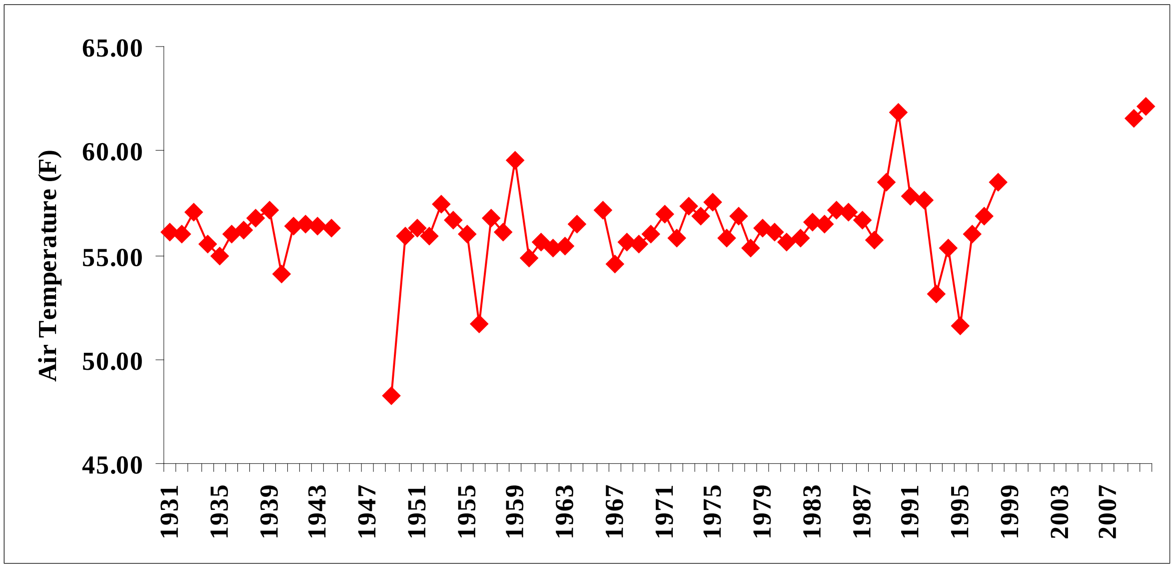
Salinity intrusion is also likely to result from sea-level rise due to the movement of the salt wedge. The average salinity at the Monie Bay Reserve was calculated to be 10.43 ± 0.18 ppt for the top and 10.51 ± 0.17 ppt for the bottom using ten discrete water quality sampling locations (Table 4.3.7; Section 4.3.6 Water quality). Current mesohaline conditions would likely shift to more polyhaline resulting in modifications in the plant species composition of this wetland system. As mentioned above, *S. alterniflora*, *J. roemerianus*, *S. patens*, *P. australis*, and *I. frutescens* are among the most predominant species in Monie Bay marshes. Higher salinities have been shown to inhibit plant growth and productivity (Broome et al. 1975); however, numerous salt marsh plants have the ability to make physiological modifications under salt stress conditions to cope with these changes.

For example, Touchette et al. (2009) exposed *S. alterniflora* and *J. roemerianus* to short and long-term salinity stresses and documented their responses providing valuable insight to future outcomes. *S. alterniflora* had a “salt-tolerant” response while *J. roemerianus* had an “avoidance response.” When exposed to high salinities, *S. alterniflora* underwent an osmotic adjustment where the tissue solute content increased. This physiological modification seems to alleviate loss of water allowing the species to survive during increased salinity pulses. *S. alterniflora* also increased its tissue rigidity by three-fold when exposed to higher salinities. More rigid leaf tissue decreases water loss through transpiration during salinity pulses further allowing it to maintain high water content within tissues. Lastly, *S. alterniflora* did not show any significant decline in leaf conductivity. In contrast, *J. roemerianus* presented physiological modifications through salt avoidance, specifically through decreased stomatal conductance and decreased water potential within the tissues. Even though both species were able to make adjustments to survive salinity pulses; salt-tolerance mechanisms yield more prolonged success compared to salt-avoidance. The salt-tolerance response mechanisms of *S. alterniflora* allow it to survive during longer-term, providing a more competitive edge. The salt-avoidance adaptations of *J. roemerianus* would need supplemental modifications in order to yield long-term survival. These response mechanisms shape current salt marsh dynamics as *S. alterniflora* would be able to persist at the marsh edge where salinities are higher while *J. roemerianus* will be pushed to the less vulnerable higher marsh locations. As salinity increases due to sea level rise, the conclusions drawn by Touchette et al. (2009) are likely to result in Monie Bay marshes.

Although increased air and water temperatures induced by climatic changes may not have a direct major impact on marshes; these changes would, however, mostly impact the subtidal zone. For example, an increase on water temperature of 1 °C will cause a decrease of 2% in the water’s capacity to dissolve oxygen (Najjar 2000). In addition, an increase on water temperature will increase bacterial production and the metabolism of aquatic organisms including invertebrates, amphibians, fish, and reptiles increasing the demand for oxygen. A larger oxygen demand in estuarine waters may then lead to anoxia, although the extent is not well known yet (Najjar 2000).

Increases in water temperatures may also have effects on phytoplankton species composition, distribution, and grazing by predators. Some toxic phytoplankton species, for example, may become more abundant under warmer temperatures (Tester 1996). Also, during warmer winters, zooplankton grazing of phytoplankton increases, which may lead to a decrease of detrital material for benthic organisms, but better oxygenation of bottom waters (Keller et al. 1999).

During a period of about 80 years (1931-2010), air temperature and precipitation from the Princess Anne region in Somerset County do not seem to show any defined trends of increasing air temperature or precipitation (Figure 4.5.9). However, more analyses are necessary to determine if the frequency and duration of drought or wet events have increased through time; as the impacts of these potential changes may be of important consideration to determine response and vulnerability of Monie Bay estuarine resources to climate change.



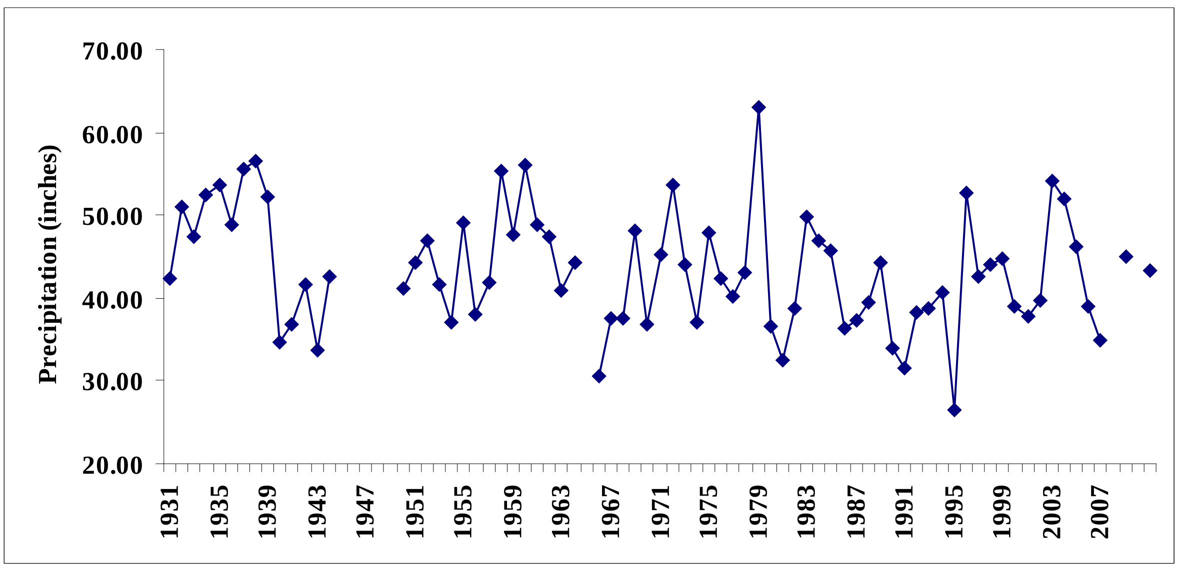


Figure 4.5.9 Annual mean temperature (°F) and precipitation (inches); Princess Anne weather station in Somerset County, Maryland. Data range: 1931-2010. Data source: National Climatic Data Center, NOAA Satellite and Information Service.

4.5.2.4. Invasive species

One of the fastest growing threats to the Chesapeake Bay is invasive species (Rice et al. 2000). Over 50,000 exotic species have been introduced to the U.S., with more added each year (Saltonstall 2002). Many exotic invasive species are threats to native plant and animal species and their habitats, including wetlands, as they invade and dominate the landscape (Saltonstall 2002). However not all invasive species pose a serious threat, and some may even provide some ecological benefits (Weinstein et al. 2002). Some of the invasive species reported for Monie Bay include *Phragmites australis* (common reed), *Myocastor coypus* (nutria), and *Cygnus olor* (mute swans), and will be discussed in more detailed in the following sections. More invasive species undoubtedly exist in Monie Bay, but there is not much information available, and they will not be discussed in this document.

Phragmites

Tidal marshes at Monie Bay, Deal Island, and the surrounding region have been invaded by a strain of *P. australis,* particularly in disturbed areas. *Phragmites australis* is a tall coarse perennial grass that grows at or above mean high water and is found worldwide in many freshwater and brackish systems. It is found all along the east coast in both tidal and non tidal wetlands and can grow in almost any habitat including lower estuaries, uplands, and even systems that are hydrological restricted like behind the dunes of barrier islands (Ailstock et al. 2001).

Phragmites has spread extensively in the past 150 to 200 years and went from being rare and uncommon in the 1800's to now existing in every mainland state of the United States, where it continues to spread and dominate by forming extensive monocultures (Saltonstall 2002, Weinstein et al. 2002). The Atlantic coast is one of the places that has been extensively colonized by *Phragmites* (Chambers et al. 1999). The exact cause of the recent spread is not well known but there are different theories. Human disturbances, aggressive genotypes, various stressors including increased nutrients, salinity and sedimentation have all been proposed as explanations for the expansion. It is also thought that there are two strains of *Phragmites*, native and non-native, with the non-native strain introduced only in the past 200 years (Saltonstall 2002, Weinstein et al. 2002).

One of the characteristics that make *Phragmites* an effective invader is that it grows very quickly both horizontally and vertically from its extensive seeding and rhizome system forming dense monotypic stands (Rice et al. 2000, Ailstock et al. 2001). In addition, *Phragmites* has many adaptations that make it a particularly good competitor. It is able to take root on undisturbed as well as disturbed soils because of the combination of seeds and rhizomes. It grows faster, sometimes up to ten meters a season, taller and thicker than other herbaceous wetland plants. This causes it to not only out-compete other plants, but actually harm them by limiting sunlight and space so that it is almost impossible for anything else to grow (Ailstock 2000). Not only does it impact plant diversity which impacts animal diversity, but also alters the biogeochemistry, hydrology, geomorphology, and trophic level. For example, by changing the marsh surface, *Phragmites* changes stream flow and sedimentation levels which impacts nutrient levels and then plants and animals (Chambers et al. 1999, Weinstein et al. 2002, Hunter et al. 2006).

Because of the fast and widespread growth of *Phragmites*, it has become increasingly difficult to control. There are different possible management techniques that have been proposed or used. Chemical control is the most effective method in a short-time period, but has no permanent success. Other methods include biocontrol (using insects), flooding, cutting, excavation and burning, all with no permanent success (Ailstock 2000, Ailstock et al. 2001). None of the methods are effective by themselves, the best way to fully eradicate *Phragmites* is through the combination of methods such as chemical control followed by burning, but such efforts are costly and time consuming (Orson 2000, Ailstock 2000).

Considering the high competitive ability of *Phragmites* and the fact that this species is very difficult to eradicate, studies have been conducted to determine the benefits this plant may provide to the marsh or other ecosystems. For example, if left alone, *Phragmites* colonizes disturbed areas that would otherwise remain bare and is able to stabilize the soil against erosion. It can also provide habitat for many different species (including birds) and acts as a nutrient sink. Overall, *Phragmites* may be used as a restoration plant in disturbed systems (Ailstock 2000).

Unfortunately, there is little research or documentation regarding *Phragmites* at Monie Bay. Routine spraying is done by Maryland DNR Wildlife and Heritage Service. In 2002, a partnership program was formed between Maryland DNR's Wildlife and Heritage Service, Maryland Department of Agriculture's Weed Management Division and Chesapeake Wildlife Heritage to offer spraying control services to landowners wishing to control *Phragmites* on their properties. Previously, services were only offered for properties larger than three acres, but in 2004, the Natural Resource Conservation Service began to offer financial aid to increase participation of private landowners in *Phragmites* eradication. In 2009 Somerset County had eight landowners participate in the program for aerial applications, which totaled 90 acres treated. There were also five landowners that participated in the truck based applications for a total of three acres treated. The combined acreage sprayed in 2009 on private lands in Somerset County totaled 93 acres (Maryland DNR 2009).

Nutria

Nutria (*Myocastor coypu*) is another non-native invasive species found in Monie Bay. The nutria is a large rodent (12-20 lbs) with grayish brownish fur and large yellow orange teeth. It inhabits many different wetland and marsh areas including both brackish and freshwater systems. They were first imported by the fur trade industry, but were released into the wild after this industry failed in the 1940s; nutria is now affecting the entire Chesapeake Bay ecosystem. Nutria, a native to South America is now found in every county of Maryland's eastern shore (U.S. Fish and Wildlife Service 2010, Guy 2007). Like many invasive species, nutria reproduce very quickly and have no natural predators which is why they have multiplied in Maryland from 250 animals in 1968 to about 35,000-50,000 today (U.S. Fish and Wildlife Service 2010).

Nutria destroy marsh surface not only by feeding on marsh plants and grasses, but also by digging down to eat the roots leaving the marsh vulnerable to erosion (U.S. Fish and Wildlife Service 2010). In addition, by damaging the marsh nutria also impacts the many animals that depend on these ecosystems for food and habitat (Guy 2007, Kendrot 2009).

In an effort to demonstrate and quantify the specific impacts of nutria in marshes, an exclosure study was conducted in the 1990's at the Blackwater National Wildlife Refuge. This was done by creating quarter-acre fenced areas that excluded nutria but allowed other animals to enter. After several growing seasons, the vegetation within the exclosures recovered, but vegetation in unfenced control plots continued to decline. This finding provided evidence that nutria was directly instrumental in marsh loss in and around the refuge, and gave insights about marsh recovery in the absence of nutria (Nutria, 2010).

Overgrazing by nutria on the Blackwater National Wildlife Refuge contributed to the conversion of over 1000 ha of emergent marsh to open water (Kendrot 2009). This alarming loss of marsh prompted passage by Congress of the Nutria Eradication and Control Act of 2003. This act authorized funding and gave rise to the Maryland Nutria Eradication Project, a program operated by U.S. Department of Agriculture-APHIS Division of Wildlife Services and managed by Maryland's Nutria Management Team: the US Fish and Wildlife Service, Maryland Department of Natural Resources, and their cooperators. APHIS began a systematic removal of nutria in Maryland marshes in 2002. The initial trappings were conducted on heavily impacted federal and state holdings along the Blackwater River.

Focused in Dorchester County, 10,000 nutria were removed from 100,000 acres, and Blackwater National Wildlife Refuge was declared nutria free (Kendrot 2009, Guy 2007). The Program then extended into other counties including Wicomico, and Somerset as well as areas around the Choptank River (Kendrot 2009). Overall, about 150,000 acres of wetlands on Delmarva have been cleared of nutria. The Program will continue to expand covering as many surrounding areas as possible to fully eradicate this harmful invasive species to help keep the remaining marshes healthy (Kendrot 2009).

Removal of nutria on the Deal Island Wildlife Management Area, including some areas in Monie Bay began in April 2007 (Haramis 2011, Steve Kendrot Person. comm. USDA-APHIS Project Manager of Maryland's Nutria Eradication Program). Removals continued through early 2008 and have continued to extract a few animals during subsequent mop up efforts. Trapping efforts have resulted in the capture of 805 nutria from the Monie Bay watershed; 694 were removed in 2007, 76 in 2008, 21 in 2009, and 14 in 2010. About 77% of those animals (623) were trapped from the National Estuary Research Reserve component in Monie Bay property. Figure 4.5.10 shows the distribution of nutria captures within the Monie Bay component boundary, the Monie Bay watershed, and surrounding watersheds in Somerset and Wicomico counties.

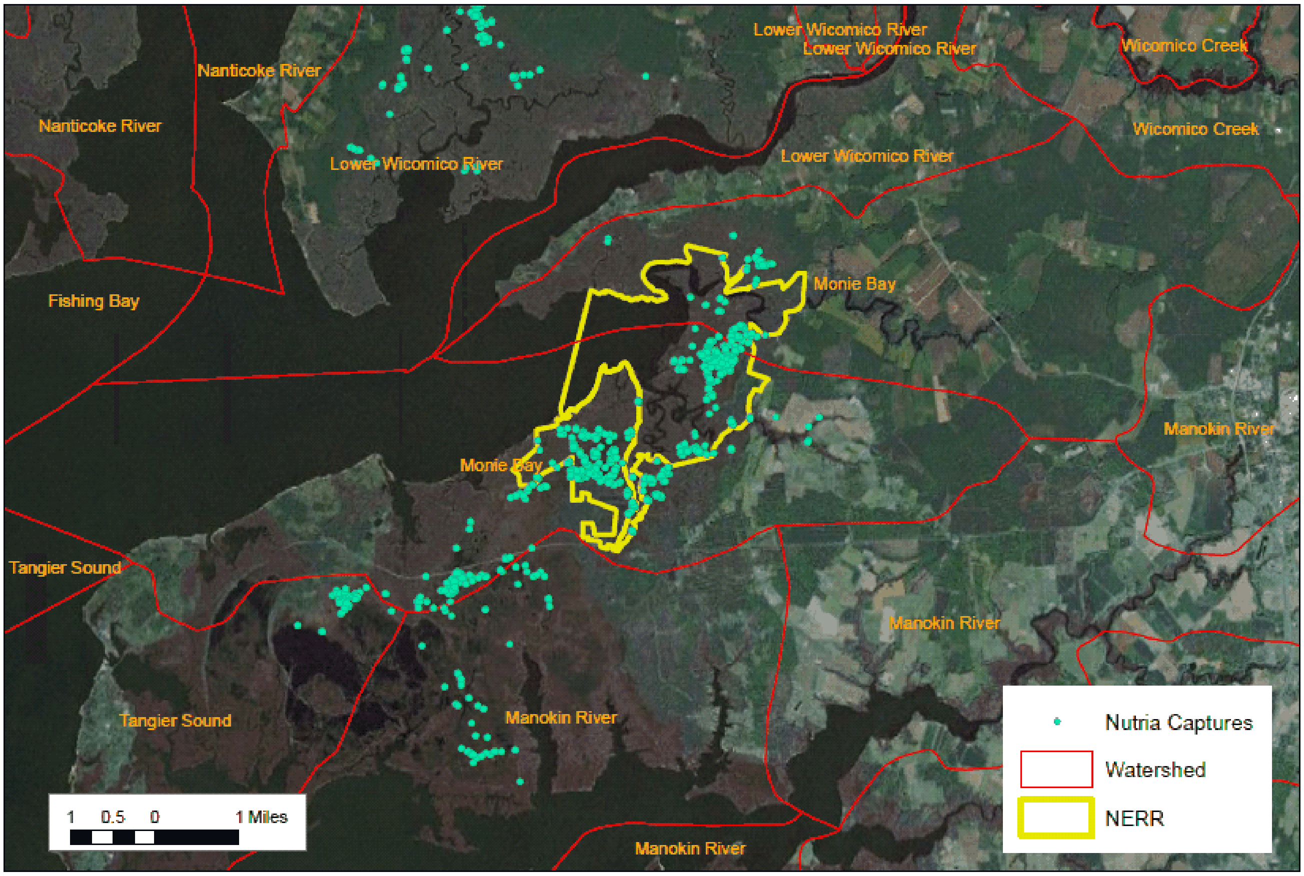


Figure 4.5.10 Distribution of nutria captured from 2007-2010 in Monie Bay watershed, Somerset County, Maryland. Produced by USDA APHIS Wildlife Services, 01/21/2011.

In 2008, Haramis (2011, unpublished data) conducted a small study within the CBNERR-MD Monie Bay component to measure the recovery of emergent marsh vegetation associated with the removal of nutria. To accomplish this, Haramis (2011, unpublished data) established fixed ½ m^2 vegetative plots in marshes dominated by *Schoenoplectus americanus* (olney three-square bulrush), the primary food of nutria within Chesapeake Bay. Plots were established along a select transect that ran from minimally impacted high marsh to heavily impacted low marsh. The transect location is shown in Figure 4.5.11.

Figure 4.5.11 Approximate location and layout of the sampling transect in Monie Bay. Transect line is 80 m in length (Map on the left). Site picture near sampling transect showing ponding produced in association with a nutria eat out. Because of water depth and ooze bottoms, such areas are difficult to re-vegetate (Haramis 2011, unpublished data).

Results from this study showed that the average vegetation cover per plot increased from 38.5% in 2008 to 44.5% in 2009, with an increase in total sampled vegetated area of 28.8% (10.4 to 13.4 m^2). A comparison of distributions of percent plot cover is shown in Figure 4.5.12. Plots with 50% or more of total cover increased from 42.6% (23 plots) in 2008 to 57.4% (31 plots) in 2009. *S. americanus* cover increased 32.2% (from total sampled area of 9.9 to 13.1 m^2) while coverage of the co-dominant species, *D. spicata*, increased an exceptional 136% (total sampled area of 2.3 to 5.4 m^2; Figure 4.5.13). Percent vegetative cover and recovery of vegetation declined along the transect gradient from high marsh to open water (Figure 4.5.14).

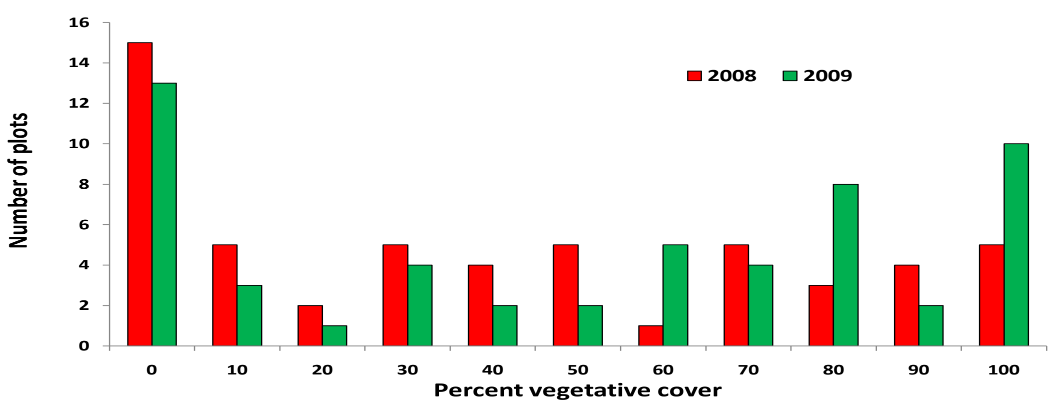


Figure 4.5.12 Comparison of distributions of percent cover for 54 fixed ½ m^2 plots along the Monie Bay transect in 2008 and 2009 (Haramis 2011, unpublished data).

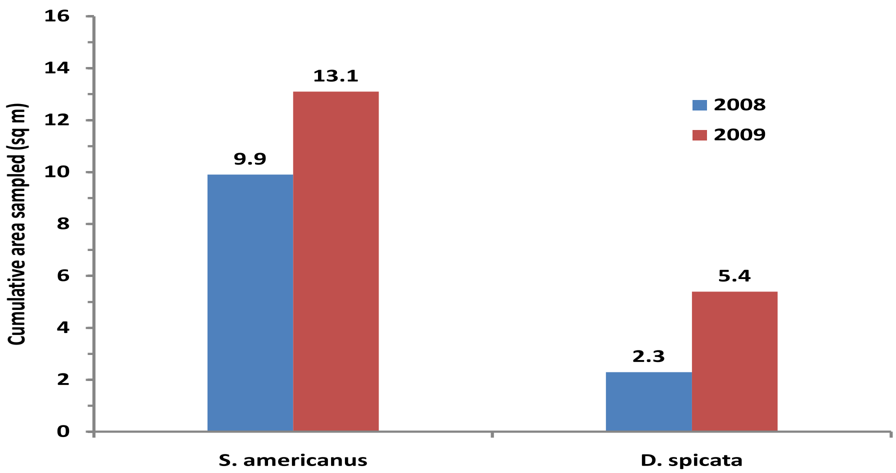


Figure 4.5.13 Coverage (m^2) of co-dominant *Schoenoplectus americanus* and *Distichlis spicata* along the Monie Bay transect between 2008 and 2009. The increase in vegetative cover occurred since removal of nutria in 2007 (Haramis 2011, unpublished data).

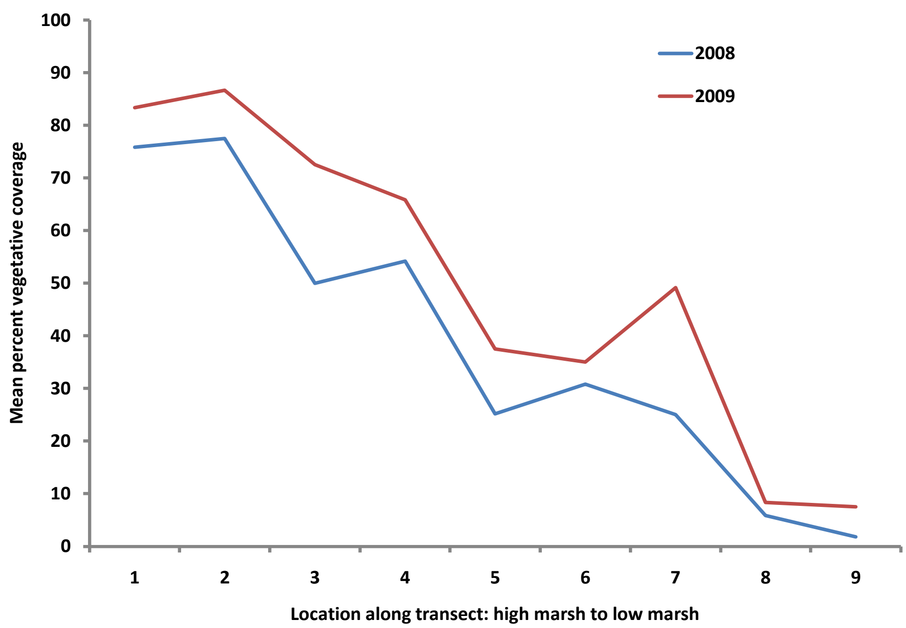


Figure 4.5.14 Comparison of mean percent total vegetative cover between 2008 and 2009 along the Monie Bay transect. Coverage declined as the transect transitioned from high marsh (left) to open water (right), a difference due mainly to declining elevation. The separation of the curves represents the mean increase in vegetative cover between the two sampling years (Haramis 2011, unpublished data).

Removal of virtually the entire nutria population in the spring of 2007 prompted a marked increase in vegetative coverage in a single growing season. Recovery was greatest in the high marsh locations of transects (sample locations 1-5: Figure above) where shallow water and firm bottom were conducive to vegetative growth versus the open water section of transects (sample locations 6-9) that had deeper water and ooze bottoms. Soft marsh surfaces are more easily damaged by nutria and resultantly are more rapidly eroded by tide and wave action. These contributing elements result in ponding and development of ooze sediments. Such areas are difficult to revegetate because of lower elevation, unconsolidated sediment, and the vulnerability of pioneering plant rhizomes to grazing herbivores, e. g., waterfowl and muskrats. Evidence from this study indicates that recovery of interior marsh proceeds rapidly with removal of nutria (Figure 4.5.15). It is predicted that vegetative cover will continue to expand in the higher marsh zones.

Figure 4.5.15 Before and after photos of *S. americanus* recovery following the removal of nutria at the CBNERR-MD Monie Bay component (Haramis 2011, unpublished data).

Mute swans
Cygnues olor (mute swans) like the nutria are a very recent invader of the Chesapeake Bay. Mute swans are native to Eurasia and were first introduced into the United States in the late 1800's (Tatu et al. 2007). They were first introduced to the Chesapeake Bay in March of 1962 when five birds from a collector in Talbot County escaped and multiplied (Maryland DNR 2003). By 1974 there were more than a 100 birds, which number remained fairly stable until 1986. From 1986 to 1999 the numbers went from 264 to 3,955 birds. It was predicted that with such growth rate there would be a population of over 30,000 mute swans by 2010 (Maryland DNR 2003).

Mute swans impact SAV as the flocks feed on it and destroy and remove it by paddling (Tatu 2007). Even though other waterfowl species also feed on SAV, they do not do it at the extent that mute swans have shown. Other waterfowl usually feeds on SAV only during the winter; mute swans, however, are in the Bay year round and do not use any other food sources to supplement their SAV consumption. As a result, SAV communities are constantly under pressure by mute swans, even during the growing season. Each bird can eat eight pounds of SAV a day (Maryland DNR 2003), and about 10.5 million pounds a year (Associated Press 2003).

By impacting SAV mute swans also impact those animals that use these communities for habitat or food source (Tatu 2007). And, considering the important role SAV plays in the health and functioning of the Bay, mute swans are therefore also threatening the entire Chesapeake Bay ecosystem (Maryland DNR 2003). Not only do mute swans impact SAV, but also other animals they interact with. They are very aggressive toward other mute swans as well as native waterfowl. With their behavior, they drive other waterfowl species away and disturb their nests by stepping on their eggs (Associated Press 2003, Tatu 2007).

In an effort to control mute swans, Maryland DNR established in 1999 the Mute Swan Task Force to determine best management practices (Maryland DNR 2003). As a result of this effort, two different methods have been put into place to try and control mute swan populations: 1) egg-addling, which started in 2001; and 2) the shooting of birds, which started in 1997, stopped and then started again in 2003 (Associated Press 2003, Maryland DNR 2003). The population decreased slightly from 1999 to 2002 (from 3,995 to 3,624 birds) due to the egg addling program, but there is no guarantee that this program will continue to have these results (Maryland DNR 2003).

Regarding mute swans in Monie Bay, there is little to no information concerning their numbers or impacts besides the fact that they do exist there. Therefore, there is a need to develop studies to better estimate population densities in this area, as well as to quantify impacts, particularly on local SAV communities.

4.6. RESEARCH AND MONITORING

Research at the CBNERR-MD Monie Bay component relates to water quality, nutrient cycling, marsh ecology, and some limited studies have looked into aquatic organisms and wildlife. Most studies have been conducted by scientists from local universities and researchers from state and local governmental organizations, and through the CBNERR-MD Graduate Research Fellowship Program. Since 2007, more research and monitoring efforts have been initiated by the Reserve's research program including monitoring of water quality, marsh emergent vegetation, and some related to marsh sedimentation dynamics. The Monie Bay estuarine system provides great ecological and economical benefits to the region; with a better understanding of this area it will be easier to implement science-based management, protection, and restoration efforts regarding its aquatic resources.

Any new Reserve's research and monitoring initiatives should be designed to:

- Fulfill information needs within Monie Bay, its tidal tributaries, and associated subwatersheds,
- Follow the short and long-term goals and objectives specified in the Reserve's research and monitoring plan, and
- Take into consideration the needs of local partners.

At the national scale, research and monitoring efforts conducted by CBNERR-MD will also follow initiatives guided by the NOAA-National Estuarine Research Reserve System.

Because of current limited availability of resources for natural science research and the remoteness of the site, the implementation of most new research and monitoring efforts will entail coordination and collaboration with local existing and new partners. The Reserve's Research program will actively engage with academic and other state and local research organizations to foment their interest in conducting projects that will address Monie Bay research needs. In an effort to increase available resources to conduct research within the Reserve and adjacent watersheds, the Research program will pursue available grants in collaboration with partners. The NERRS Graduate Research Fellowship program will continue to provide additional opportunities to address research needs within this component.

4.6.1. Research Facilities

There are two main facilities near and within the Monie Bay. One is the Maryland DNR Wildlife and Heritage Service office at Wellington Wildlife Management Area, Princess Anne. This facility is located about a 25-minute drive from the Reserve, and it provides some basic space and equipment (e.g. boat and motor for field sampling) that can be used by our program to implement some of our research and monitoring programs. The second one is a property that was recently purchased and that will be incorporated as part of the Reserve (Phillips property). This property includes a house and a small pier, providing space for lodging and easy access to the water and marsh. Both facilities currently provide space to do basic water quality filtering, working space, and storage area.

Currently, access to the Monie Bay component can be done by water (three access points) or by land (one access point). One water access point is located at the end of Drawbridge road, where the road ends in the water. This has no real boat ramp or pier, but because of its proximity to the reserve component, it is the most used by the CBNERR-MD research staff. The second water access point is the Dames Quarter boat ramp and pier, but this location is farther from the actual Monie Bay component and is not used very much. The third access is through the newly acquired Phillips property, which provides two additional access points to the Reserve: (1) by land, through a small road off Drawbridge road and (2) by water, through a small pier connected to Little Monie Creek, which once refurbished will be used as an additional easy access area for partners and CBNERR-MD staff to the water and marsh.

4.6.2 Research and Monitoring Needs

Research and monitoring needs for the Monie Bay component listed in this section were identified based on different sources including the CBNERR-MD management plan, reports and peer review papers highlighting information gaps, informal conversations with state staff and other researchers working in this area, and recommendations from Reserve's research program staff based on their on-site knowledge. However, to develop a more comprehensive list of research and monitoring needs for Monie Bay, the CBNERR-MD research staff anticipates planning in 2012 a workshop with Reserve staff, partners, local resource managers, academia, and other interested parties to identify and prioritize research and monitoring needs that would address priority management needs within this region.

Currently and in the near future, research, and monitoring activities at Monie Bay will be directed at assessing the current ecological state of the component's natural resources and monitor any potential changes due to anthropogenic activities and climate change, particularly sea level rise. The current approach to address these issues is the continuation of in-place long-term monitoring projects, including water quality, emergent vegetation, and marsh surface elevation dynamics monitoring. Expansion of monitoring efforts will be considered to involve the transitional area between the estuary and terrestrial habitats and to include sampling sites within the three Monie Bay tidal tributaries (Monie Creek, Little Monie Creek, Little Creek).

Monie Bay, as a sub-estuary of Chesapeake Bay and a tributary of Tangier Sound serves ideally as a natural laboratory to link land use to aquatic processes and downstream water quality. Monie Bay ecosystem includes three tidal creeks differing only by the surrounding land use. Such land use configuration allows direct comparisons for example of nitrogen sources from poultry farm runoff (Little Monie Creek), crop agriculture (Monie Creek, near the border of the estuarine reserve), and a sub-watershed dominated by wetlands and forests (Little Creek, used as a reference). While land use in the watersheds of Monie Creek (45.0 km^2) and Little Monie Creek (17.9 km^2) are similar, with over 50% forest cover, only 3% developed and the remainder roughly split between wetlands and agriculture, comparisons of nitrogen sources can be made between septic and poultry (Monie Creek) and crop agriculture (Little Monie Creek) due to minimal residential development or poultry production in the Little Monie Creek watershed. Little Creek, with the smallest sub-watershed (9.4 km^2) is dominated by wetlands (63%) and forests (35%), and can be used as a reference creek as virtually no agriculture (1%) or development (1%) is present.

More specific research and monitoring needs organized by biological component are presented in the following sections.

4.6.2.1 Brackish marsh

Some research and monitoring is already underway to continue characterizing and monitoring Monie Bay marshes and their response to climate change and anthropogenic activities (e.g., agriculture, poultry farming, tree farming). Of particular importance is to develop climate change vulnerability assessments at the species and ecosystem level to better inform management and protection efforts in this area.

The development of GIS projects, particularly habitat mapping and change analyses, will be vital for determining the impact of development and land use changes on Monie Bay aquatic and upland resources. Additionally, analyses of aerial imagery involving shoreline movement would provide information on erosion and or expansion of the tidal creek network of this estuarine system. It would also be important to explore the severity of marsh erosion in more detailed while determining spatial and temporal variability and its relationship to storms and other climatic events.

More studies are needed to determine the past distribution, current status, and potential expansion of invasive species at Monie Bay, particularly common reed. It is also important to develop a comprehensive inventory of aquatic grasses while determining their distribution, species composition, and status as well as their role in sediment retention, nutrient cycling, water quality, nursery habitat, food source, etc.

4.6.2.2 Upland vegetation community

To our knowledge there is essentially no scientific information describing or analyzing the upland habitats of the Monie Bay watershed. Trees, grasses, and herbaceous plants and their associations have not been studied. Soil and groundwater biogeochemistry have not been described for forests, natural fields, or agricultural plots in the region.

More information regarding Monie Bay's upland vegetation community is needed; starting with a comprehensive inventory of species present to studies regarding their function particularly under projected environmental and climatic changes, for example, carbon sequestration, primary productivity, nutrient cycling, natural regeneration. Also, it is important to evaluate the role of the upland vegetation communities in Monie Bay as natural corridors for wildlife. Comparisons between tree farms and more natural forest systems may draw important information to guide management efforts.

Establish an effort to monitor invasive species, existing and new, is important to guide any control efforts, particularly in the face of predicted changes on temperature and precipitation patterns.

4.6.2.3 Microbiological components

Almost any research and/or monitoring effort to study the microbial communities within Monie Bay, particularly its wetlands, would be an addition to existing information on these communities. Current water quality monitoring efforts conducted by the Reserve do not include the sampling of fecal coliforms. Considering the health issues associated with their presence, it would be an important component to add to the suite of parameters currently being monitored.

Considering predicted climatic changes, it would be important to determine how changes in precipitation patterns, intense drought conditions, and changes in salinity may impact the populations of bacteria in the water and sediments of the Monie Bay estuarine system.

4.6.2.4 Plankton

Although considerable information is available about the plankton communities of different areas within the Chesapeake Bay, little is known about the particular communities present in Monie Bay, their dynamics and interactions. Basic studies are much needed to determine the species composition, abundance, biomass, and productivity of the phytoplankton and zooplankton communities in this area. Further research is also needed to determine the interrelationships between Monie Bay's plankton components and water quality and physical and chemical environmental factors. Plankton food webs are poorly understood, as is the role of marsh production in regulating them

In addition to gather basic information on plankton species composition and abundance, it would be important to monitor these communities to determine species shifts due to invasive species and to evaluate responses to potential climate and land use changes. Monitoring of potentially harmful phytoplankton species is of particular interest. For example, how phytoplankton community structure and distribution changes as a result of varying levels of nutrient concentrations (nitrogen and phosphorus), salinity, and temperature through space and time.

4.6.2.5 Benthic macroinvertebrates

Presently, there is very limited information regarding the specific benthic macroinvertebrate community of Monie Bay. A first priority is to conduct a comprehensive baseline characterization including species composition and abundance in different substrates and habitats within the estuary. Aquatic insects and benthic invertebrates constitute food supply for fish, waterfowl, and other organisms and there is limited knowledge of what is there or their relative abundances. In addition, studies to analyze trophic relationships and relationships between species presence and abundance and local environmental parameters would be valuable to evaluate habitat condition and to determine which factors affect population structure of benthic communities in Monie Bay.

Similarly, conducting studies in both the marsh and open water is important to determine natural spatial and temporal population changes and to evaluate the potential responses to anthropogenic and natural stressors. Developing comparative studies among Monie Creek, Little Monie Creek, and Little Creek would be of particular interest especially because of their differences in subwatershed land use related stressors. Of importance in this area is to study the potential impacts from agriculture, specifically from the use of various herbicides and pesticides. Monitoring these communities is also valuable to detect the presence of invasive species and community shifts as a response to climate change.

More research is also needed regarding the local Monie Bay populations of other important macroinvertebrates including the blue crab and the eastern oyster. A better quantification of their populations as well as their current status is needed to guide any restoration or management efforts in this region of the Chesapeake Bay.

4.6.2.6 Fish, reptiles, and amphibians

Little information is available regarding fish, reptiles, and amphibians specific to Monie Bay. Information is needed regarding complete species lists, species distribution, population density and status, habitat requirement, feeding habits, and general population dynamics.

Because of their highly recognized economical and ecological value, it is of particular interest to Monie Bay to study fish populations, including specific interactions between key fish species and various estuarine habitats, foodweb interrelationships, and population responses to natural and anthropogenic impacts including poor water quality, heavy metal contamination, and climate change. How the reproductive cycle and development of fish species (particularly those of economic and high ecological value) as well as their migration and feeding patterns would be impacted by changes in salinity and water temperature are research needs of interest due to current climate change scenarios. In addition, more information is needed regarding the potential impacts of commercial and recreational fishing on Monie Bay fish stocks and their collateral damage to other aquatic species.

4.6.2.7 Birds and mammals

Studies of specific bird and mammal species occurring at Monie Bay are relatively limited. How different species of water birds use wetlands throughout the year, their food sources, habits, population sizes, and their responses to a changing environment are areas of research that need more exploration for Monie Bay populations.

In addition to the need for a complete list of species, not very much is known about the mammals' populations at Monie Bay. Of particular interest for research and/or monitoring are populations of nutria and muskrats. Learning more about these species, their population density, feeding habits, and habitat use is important as they seem to play an important role in wetland stability. Developing studies to learn more about the least common species of mammals would also enrich the knowledge of Monie Bay's wildlife.

4.6.2.8 Other research and monitoring needs

During the last 10-20 years there has been a range of scientific studies of particular aspects of the Monie Bay system; however, there is much that remains to be done. Atmospheric inputs to the watershed are unknown, as are ecological processes that regulate gas exchange between the watershed and the overlying atmosphere.

The water circulation of tidal creeks and open bays of the Monie system has not been measured or modeled, and there is not much information on water residence times for any of the three tidal creek systems. A complete sediment and nutrient budget for this system is also lacking.

Basic information on marsh plant ecology and sediment biogeochemistry is available; however, little is known about marsh interactions with the watershed and estuary. The study and monitoring of groundwater resources within the Monie Bay area has been somewhat underestimated compared with surface waters. There is a need to learn more about this resource, particularly regarding groundwater contamination, potential for salinization, and the potential compounding impacts of human uses and climate change on groundwater levels.

Finally, an integrative understanding of the Monie Bay Reserve component as an ecosystem is totally lacking, where system level biogeochemical cycles, food webs, and community dynamics are not well described nor are the interactions between processes at ecosystem, community, and population levels. The ecological services and economic value of the Monie Bay system are not well understood, and the socioeconomic impact of the reserve is poorly described.

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APPENDIX I

Partial list of species found in Otter Point Creek, Chesapeake Bay National Estuarine Research Reserve. Species are organized by order, family, scientific name, common name, and status.

Invertebrate Species List

Order	Family	Scientific Name	Common Name
Amphipoda (Amphipods)	Crangonyctidae	*Crangonyx* spp.	
	Gammaridae	*Gammarus* spp.	
Basommatophora	Physidae	*Physella* spp.	
Coleoptera (Beetles)	Elmidae (Riffle beetles)	*Ancyronyx* spp.	
		Dubiraphia spp.	
		Macronychus spp.	
		Microcylloepus spp.	
		Oulimnius spp.	
	Haliplidae (Crawling water beetles)	*Peltodytes* spp.	
	Hydrophilidae (Water scavenger beetles)	*Berosus* spp.	
	Psephenidae (Water-penny beetles)	*Psephenus* spp.	
Decapoda (Crayfish, crabs, lobsters, shrimp)	Cambaridae (Crayfishes)	*Cambarus* spp.	
		Orconectes limosus	Spinycheek crayfish
		Orconectes virilis	Virile crayfish
		Procambarus acutus	White river crayfish
	Palaemonidae	*Palaemonetes pugio*	Dagger blade grass shrimp
	Panopeidae (Mud crabs)	*Panopeus herbstii*	Black-fingered mud crab
	Portunidae (Swimming crabs)	*Callinectes sapidus*	Blue crab
Diptera (Gnats, mosquitoes, and true flies)	Ceratopogonidae (Biting midges, no-see-ums, punkies)		
	Chironomidae (Midges)	*Cardiocladius* spp.	
		Chironomus spp.	
		Cricotopus spp.	
		Cryptochironomus spp.	
		Cryptotendipes spp.	
		Diamesa spp.	
		Dicrotendipes spp.	
		Endochironomus spp.	

Order	Family	Scientific Name	Common Name
		Eukiefferiella spp.	
		Hydrobaenus spp.	
		Microtendipes spp.	
		Nanocladius spp.	
		Orthocladius spp.	
		Parachironomus spp.	
		Parametriocnemus spp.	
		Paraphaenocladius spp.	
		Paratendipes spp.	
		Phaenopsectra spp.	
		Polypedilum spp.	
		Rheocricotopus spp.	
		Rheotanytarsus spp.	
		Stempellinella spp.	
		Stictochironomus spp.	
		Tanytarsus spp.	
		Thienemannimyia spp.	
		Trissopelopia spp.	
		Tribelos spp.	
		Tvetenia spp.	
	Empididae (Balloon flies, dance flies)	*Hemerodromia* spp.	
	Simuliidae (Black flies, buffalo gnats)	*Prosimulium* spp.	
		Simulium spp.	
	Tipulidae (Crane flies, tipules)	*Antocha sp.*	
		Tipula spp.	
	Naididae		
Ephemeroptera (Mayflies)	Ephemerellidae	*Ephemerella* spp.	
		Eurylophella spp.	
		Serratella spp.	
	Heptageniidae	*Stenonema* spp.	
	Isonychiidae	*Isonychia* spp.	
Gordioidea	Gordiidae		
Haplotaxida	Tubificidae	*Limnodrilus sp.*	
		Spirosperma sp.	
Hemiptera (Hemipterans, true bugs)	Belostomatidae (Electric light bugs, giant water bugs)	*Belostoma sp.*	
Hoplonemertea	Tetrastemmatidae	*Prostoma* spp.	
Lepidoptera (Butterflies,	Pyralidae (Grass moths,		

Order	Family	Scientific Name	Common Name
moths)	snout moths)		
Lumbriculida	Lumbriculidae		
Megaloptera	Corydalidae (Dobsonflies, fishflies, hellgrammites)	*Nigronia* spp.	
Myoida	Myidae	*Mya arenaria*	Softshell clam
Odonata	Calopterygidae (Broad-winged damselflies)	*Calopteryx* spp.	
	Coenagrionidae (Narrow-winged damselflies, pond damsels)		
	Corduliidae (Emeralds, green-eyed skimmers)	*Macromia* spp.	
	Gomphidae (Clubtails)	*Hagenius* spp.	
Plecoptera	Perlodidae (Perlodid stoneflies)		
Rhynchobdellida	Piscicolidae		
Trichoptera (Caddisflies)	Brachycentridae	*Micrasema* spp.	
	Hydropsychidae (Net-spinning caddisfishes)	*Cheumatopsyche* spp.	
		Hydropsyche spp.	
	Philopotamidae (Finger-net caddisflies)	*Chimarra* spp.	
Tricladida (Triclads)	Planariidae	*Dugesia* spp.	
Veneroida	Corbiculidae	*Corbicula* spp.	
	Pisidiidae (Peaclams)	*Sphaerium* spp.	
	Veneridae	*Mercenaria mercenaria*	
Unionida	Unionidae		

Amphibian Species List

Order	Family	Scientific Name	Common Name	Status
Anura (Frogs, toads)	Bufonidae (Toads)	*Anaxyrus americanus americanus*	Eastern American toad	P,N
	Hylidae (Hylid frogs, Hylids, New World tree frogs, treefrogs)	*Acris crepitans*	Northern cricket frog	P,N
		Hyla versicolor	Gray tree frog	R,N
		Pseudacris crucifer	Spring peeper	P,N
	Ranidae (Ranid frogs, Ranids, true frogs)	*Lithobates catesbeianus*	American bullfrog	P,N,E
		Lithobates clamitans	Green frog	P,N
		Lithobates palustris	Pickerel frog	R,N

Order	Family	Scientific Name	Common Name	Status
		Lithobates sphenocephalus sphenocephalus	Florida leopard frog	P,N
		Lithobates sylvaticus	Wood frog	P,N
Caudata (Salamanders)	Ambystomatidae (Mole salamanders)	*Ambystoma maculatum*	Spotted salamander	R,N
		Ambystoma opacum	Marbled salamander	R,N
	Plethodontidae (Lungless salamanders)	*Eurycea bislineata*	Eastern two-lined salamander	R,N
		Plethodon cinereus	Redback salamander	A,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Reptile Species List

Order	Family	Scientific Name	Common Name	Status
Squamata (Lizards, amphisbaenians and snakes)	Colubridae (Colubrids, typical snakes)	*Carphophis amoenus*	Eastern worm snake	P,N
		Coluber constrictor	Black racer	P,N
		Diadophis punctatus	Northern ringneck snake	P,N
		Elaphe obsoleta	Black rat snake	P,N
		Nerodia sipedon	Northern water snake	P,N
		Opheodrys aestivus	Rough green snake	R,N
		Thamnophis sauritus	Ribbon snake	P,N,E
		Thamnophis sirtalis	Eastern garter snake	P,N
		Storeria dekayi	Brown Snake	R,N
	Phrynosomatidae (North American spiny lizards)	*Sceloporus undulatus*	Eastern Fence lizard	P,N
	Scinidae (Skinks)	*Eumeces fasciatus*	Five-lined skink	P,N
		Eumeces laticeps	Broadhead skink	P,N
Testudines (Terrapins, tortoises, turtles)	Chelydridae (Snapping turtles)	*Chelydra serpentina*	Snapping turtle	P,N
	Emydidae (Emydid turtles, pond turtles, terrapins)	*Chrysemys picta*	Eastern painted turtle	P,N
		Trachemys scripta elegans	Red-eared slider	R,N
		Clemmys guttata	Spotted turtle	U,N
		Pseudemys rubriventris	Redbelly turtle	R,N
		Terrapene carolina	Eastern box turtle	P,N
	Kinodternidae (Musk turtles, mud turtles)	*Kinosternon subrubrum*	Eastern mud turtle	R,N
		Sternotherus odoratus	Common musk turtle (Stinkpot)	R,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Fish Species List

Order	Family	Scientific Name	Common Name	Status
Anguilliformes (Eels)	Anguillidae (Freshwater eels)	*Anguilla rostrata*	American eel	P,N
Atheriniformes (Silversides)	Atherinidae (New World silversides)	*Menidia beryllina*	Inland silverside	P,N
		Menidia menidia	Atlantic silverside	P,N
Beloniformes (Needlefishes)	Belonidae (Needlefishes)	*Strongylura marina*	Atlantic needlefish	R,N
Clupeformes (Anchovies, herrings)	Clupeidae (Herrings, menhadens, sardines, shads, sprats)	*Alosa aestivalis*	Blueback herring	R,N
		Alosa pseudoharengus	Alewife	P,N
		Alosa sapidissima	American shad	P,N
		Brevoortia tyrannus	Atlantic menhaden	P,N
		Dorosoma cepedianum	Gizzard shad	A,N
	Engraulidae (Anchovies)	*Anchoa mitchilli*	Bay anchovy	R,N
Cypriniformes (Minnows, suckers)	Castostomidae (Suckers)	*Catostomus commersonii*	White sucker	P,N
		Erimyzon oblongus	Creek chubsucker	P,N
		Hypentelium nigricans	Northern hog sucker	P,N
	Cyprinidae (Carps, minnows)	*Campostoma anomalum*	Central stoneroller	P,N
		Carassius auratus	Goldfish	P,N
		Cyprinus carpio	Common carp	P,N
		Exoglossum maxillingua	Cutlips minnow	R,N
		Hybognathus regius	Silvery minnow	P,N
		Luxilus cornutus	Common shiner	P,N
		Notemigonus crysoleucas	Golden shiner	P,N
		Notropis hudsonius	Spottail shiner	P,N
		Pimephales notatus	Bluntnose minnow	U,N
		Rhinichthys atratulus	Eastern blacknose dace	R,N
		Rhinichthys cataractae	Longnose dace	U,N
		Semotilus atromaculatus	Creek chub	P,N
		Semotilus corporalis	Fallfish	U,N
	Fundulidae (Killifishes, top minnows)	*Fundulus diaphanus*	Banded killifish	P,N
		Fundulus heteroclitus	Mummichog	P,N
Esociformes (Mud minnows, pikes)	Esocidae (Pikes)	*Esox niger*	Chain pickerel	U,N
Perciformes (Perch-like fishes)	Centrarchidae (Sunfishes)	*Enneacanthus gloriosus*	Blue-spotted sunfish	P,N
		Lepomis gibbosus	Pumpkinseed	A,N

Order	Family	Scientific Name	Common Name	Status
		Lepomis macrochirus	Bluegill	P,N,E
		Micropterus salmoides	Largemouth bass	P,N
		Pomoxis nigromaculatus	Black crappie	P,N
	Moronidae (Temperate basses)	*Morone americana*	White perch	A,N
		Morone saxatilis	Striped bass	P,N
	Percidae (True perches)	*Etheostoma olmstedi*	Tessellated darter	P,N
		Perca flavescens	Yellow perch	P,N
	Sciaenidae (Coakers, croakers, drums)	*Leiostomus xanthurus*	Spot	P,N
		Micropogonias undulatus	Atlantic croaker	R,N
Pleutonectiformes (Flatfish, flounders, soles)	Achiridae (American soles)	*Trinectes maculatus*	Hogchoker	R,N
Siluriformes (Catfishes)	Ictaluridae (Bullhead catfishes, North American freshwater catfishes)	*Ameiurus catus*	White catfish	R,N
		Ameiurus nebulosus	Brown bullhead catfish	P,N
		Ameiurus platycephalus	Flat bullhead	P,N
		Ictalurus punctatus	Channel catfish	P,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Bird Species List

Order	Family	Scientific Name	Common Name	Status
Anseriformes (Waterfowl)	Anatidae (Waterfowl)	*Aix sponsa*	Wood duck	A,N
		Anas acuta	Northern pintail	P,N
		Anas americana	American wigeon	P,N
		Anas crecca	Green-winged teal	P,N
		Anas discors	Blue-winged teal	R,N
		Anas platyrhynchos	Mallard	A,N
		Anas rubripes	American black duck	P,N
		Aythya affinis	Lesser scaup	P,N
		Aythya americana	Redhead	P,N
		Aythya collaris	Ring-necked duck	P,N
		Aythya valisineria	Canvasback	P,N
		Branta canadensis	Canada goose	P,I
		Bucephala albeola	Bufflehead	P,N
		Bucephala clangula	Common goldeneye	P,N
		Cygnus columbianus	Tundra swan	R,I

Order	Family	Scientific Name	Common Name	Status
		Cygnus olor	Mute swan	P,I
		Lophodytes cucullatus	Hooded merganser	P,N
		Mergus merganser	Common merganser	P,N
		Mergus serrator	Red-breasted merganser	P,N
		Oxyura jamaicensis	Ruddy duck	P,N
Apodiformes (Swifts and hummingbirds)	Apodidae (Swifts)	*Chaetura pelagica*	Chimney swift	U,N
	Trochilidae (Hummingbirds)	*Archilochus colubris*	Ruby-throated hummingbird	P,N
Ciconiiformes (Herons, plovers, storks bitterns, ibises, and flamingos)	Accipitridae (Hawks and eagles)	*Accipiter cooperii*	Cooper's hawk	R,N
		Accipiter striatus	Sharp-shinned hawk	P,N
		Buteo jamaicensis	Red-tailed hawk	P,N
		Buteo lineatus	Red-shouldered hawk	P,N
		Buteo platypterus	Broad-winged hawk	P,N
		Circus cyaneus	Northern harrier	P,N
		Haliaeetus leucocephalus	Bald eagle	P,N
		Pandion haliaetus	Osprey	P,N
	Ardeidae (Herons and bitterns)	*Ardea alba*	Great egret	P,N
		Ardea herodias	Great blue heron	P,N
		Botaurus lentiginosus	American bittern	R,N
		Bubulcus ibis	Cattle egret	R,N
		Butorides virescens	Green heron	P,N
	Ciconiidae (American vultures)	*Cathartes aura*	Turkey vulture	P,N
		Coragyps atratus	Black vulture	P,N
	Charadriidae (Plovers)	*Charadrius vociferus*	Killdeer	P,N
	Falconidae (Falcons)	*Falco sparverius*	American kestrel	P,N
	Laridae (Gulls and terns)	*Larus argentatus*	Herring gull	P,N
		Larus atricilla	Laughing gull	R,N
		Larus delawarensis	Ring-billed gull	P,N
		Larus marinus	Great Black-backed Gull	P,N
		Larus philadelphia	Bonaparte's gull	R,N
		Sterna antillarum	Least tern	P,N,T
		Sterna caspia	Caspian tern	P,N
		Sterna forsteri	Forster’s tern	P,N
	Phalacrocoracidae (Cormorants)	*Phalacrocorax auritus*	Double-crested cormorant	P,N
	Podicipedidae (Grebes)	*Podilymbus podiceps*	Pied-billed grebe	P,N
	Scolopacidae (Sandpipers)	*Actitis macularius*	Spotted sandpiper	P,N
		Calidris melanotos	Pectoral sandpiper	U,N

Order	Family	Scientific Name	Common Name	Status
		Calidris minutilla	Least sandpiper	R,N
		Calidris pusilla	Semipalmated sandpiper	R,N
		Gallinago delicata	Wilson's snipe	P,N
		Scolopax minor	American woodcock	R,N
		Tringa flavipes	Lesser yellowlegs	R,N
		Tringa melanoleuca	Greater yellowlegs	P,N
		Tringa solitaria	Solitary sandpiper	P,N
	Threskiornithidae (Ibises and Spoonbills)	*Plegadis falcinellus*	Glossy ibis	R,N
Columbiformes (Pigeons and doves)	Columbidae (Pigeons and doves)	*Columba livia*	Rock pigeon	P,N
		Zenaida macroura	Mourning dove	P,N
Coraciiformes (Kingfishers)	Alcedinidae (Kingfishers)	*Megaceryle alcyon*	Belted kingfisher	P,N
Cuculiformes (Cuckoos)	Cuculidae (Cuckoos)	*Coccyzus americanus*	Yellow-billed cuckoo	P,N
		Coccyzus erythropthalmus	Black-billed cuckoo	R,N
Galliformes (Grouse, quail and turkeys)	Odontophoridae (Quails)	*Colinus virginianus*	Northern bobwhite	R,N
Gruiformes (Cranes, limpkins, and rails)	Rallidae (Rails)	*Fulica americana*	American coot	P,N
		Porzana carolina	Sora	R,N
		Rallus limicola	Virginia rail	R,N
Passeriformes (Perching Birds, Swallows, jays, crows, thrushes and warblers)	Bombycillidae (Waxwings)	*Bombycilla cedrorum*	Cedar waxwing	R,N
	Cardinalidae (Cardinals)	*Cardinalis cardinalis*	Northern cardinal	P,N
		Passerina caerulea	Blue grosbeak	U,N
		Passerina cyanea	Indigo bunting	P,N
	Certhiidae (Creepers)	*Certhia americana*	Brown creeper	P,N
		Polioptila caerulea	Blue-gray gnatcatcher	P,N
	Corvidae (Jays and crows)	*Corvus brachyrhynchos*	American crow	A,N
		Corvus ossifragus	Fish crow	P,N
		Cyanocitta cristata	Blue jay	A,N
	Emberizidae (Sparrows)	*Junco hyemalis*	Dark-eyed junco	P,N
		Melospiza georgiana	Swamp sparrow	P,N,C
		Melospiza melodia	Song sparrow	P,N
		Pipilo erythrophthalmus	Eastern towhee	U,N
		Spizella passerina	Chipping sparrow	U,N
		Spizella pusilla	Field sparrow	R,N
		Zonotrichia albicollis	White-throated sparrow	A,N
		Zonotrichia leucophrys	White-crowned sparrow	P,N
	Fringillidae (Finches)	*Carduelis tristis*	American goldfinch	P,N

Order	Family	Scientific Name	Common Name	Status
		Carpodacus mexicanus	House finch	P,N
	Hirundinidae (Swallows)	*Hirundo rustica*	Barn swallow	A,N
		Progne subis	Purple martin	R,N
		Tachycineta bicolor	Tree swallow	P,N
		Stelgidopteryx serripennis	Northern rough-winged swallow	R,N
	Icteridae (Blackbirds)	*Agelaius phoeniceus*	Red-winged blackbird	A,N
		Dolichonyx oryzivorus	Bobolink	R,N
		Euphagus carolinus	Rusty blackbird	P,N
		Icterus galbula	Baltimore oriole	P,N
		Icterus spurius	Orchard oriole	P,N
		Molothrus ater	Brown-headed cowbird	P,N
		Quiscalus quiscula	Common grackle	A,N
		Sturnella magna	Eastern meadowlark	R,N
	Mimidae (Mockingbirds and Thrashers)	*Dumetella carolinensis*	Gray catbird	A,N
		Mimus polyglottos	Northern mockingbird	P,N
		Toxostoma rufum	Brown thrasher	U,N
	Paridae (Titmice)	*Baeolophus bicolor*	Eastern tufted titmouse	P,N
		Poecile atricapillus	Black-capped chickadee	R,N
		Poecile carolinensis	Carolina chickadee	P,N
	Parulidae (Wood warblers)	*Dendroica pinus*	Pine warbler	P,N
		Dendroica caerulescens	Black-throated blue warbler	P,N
		Dendroica castanea	Bay-breasted warbler	R,N
		Dendroica cerulea	Cerulean warbler	R,N
		Dendroica coronata	Yellow-rumped warbler	P,N
		Dendroica discolor	Prairie warbler	P,N
		Dendroica fusca	Blackburnian warbler	R,N,T
		Dendroica magnolia	Magnolia warbler	P,N
		Dendroica palmarum	Palm warbler	R,N
		Dendroica pensylvanica	Chestnut-sided warbler	R,N
		Dendroica petechia	Yellow warbler	P,N
		Dendroica striata	Blackpoll warbler	P,N
		Dendroica virens	Black-throated green warbler	P,N
		Geothlypis trichas	Common yellowthroat	P,N
		Helmitheros vermivorum	Worm-eating warbler	P,N
		Icteria virens	Yellow-breasted chat	R,N
		Mniotilta varia	Black-and-white warbler	R,N

Order	Family	Scientific Name	Common Name	Status
		Oporornis formosus	Kentucky warbler	P,N
		Parula americana	Northern parula	P,N
		Protonotaria citrea	Prothonotary warbler	R,N
		Seiurus aurocapillus	Ovenbird	P,N
		Seiurus motacilla	Louisiana waterthrush	P,N
		Seiurus noveboracensis	Northern waterthrush	R,N
		Setophaga ruticilla	American redstart	R,N
		Vermivora ruficapilla	Nashville warbler	R,N,C
	Passeridae (Sparrows)	*Passer domesticus*	House sparrow	A,N
	Regulidae (Kinglets)	*Regulus calendula*	Ruby-crowned kinglet	R,N
		Regulus satrapa	Golden-crowned kinglet	P,N
	Sittidae (Nuthatches)	*Sitta canadensis*	Red-breasted nuthatch	P,N
		Sitta carolinensis	White-breasted nuthatch	P,N
	Sturnidae (Starlings)	*Sturnus vulgaris*	European starling	A,I
	Thraupidae (Tanagers)	*Piranga olivacea*	Scarlet tanager	P,N
		Piranga rubra	Summer tanager	R,N
	Troglodytidae (Wrens)	*Cistothorus palustris*	Marsh wren	P,N
		Thryothorus ludovicianus	Carolina wren	P,N
		Troglodytes aedon	House wren	P,N
	Turdidae (Thrushes)	*Catharus fuscescens*	Veery	R,N
		Catharus guttatus	Hermit thrush	P,N
		Catharus ustulatus	Swainson's thrush	R,N
		Hylocichla mustelina	Wood thrush	P,N
		Sialia sialis	Eastern bluebird	P,N
		Turdus migratorius	American robin	A,N
	Tyrannidae (Flycatchers)	*Contopus virens*	Eastern wood-pewee	P,N
		Empidonax alnorum	Alder flycatcher	R,N
		Empidonax minimus	Least flycatcher	R,N
		Empidonax traillii	Willow flycatcher	R,N
		Empidonax virescens	Acadian flycatcher	P,N
		Myiarchus crinitus	Great creasted flycatcher	P,N
		Sayornis phoebe	Eastern phoebe	P,N
		Tyrannus tyrannus	Eastern kingbird	P,N
	Vireonidae (Vireos)	*Vireo flavifrons*	Yellow-throated vireo	P,N
		Vireo gilvus	Warbling vireo	R,N
		Vireo griseus	White-eyed vireo	P,N
		Vireo olivaceus	Red-eyed vireo	P,N
		Vireo solitarius	Blue-headed vireo	U,N
Piciformes (Woodpeckers)	Picidae (Woodpeckers)	*Colaptes auratus*	Northern flicker	P,N

Order	Family	Scientific Name	Common Name	Status
		Dryocopus pileatus	Pileated woodpecker	R,N
		Melanerpes carolinus	Red-bellied woodpecker	P,N
		Picoides pubescens	Downy woodpecker	P,N
		Picoides villosus	Hairy woodpecker	R,N
		Sphyrapicus varius	Yellow-bellied sapsucker	R,N
Strigiformes (Owls)	Caprimulgidae (Nightjars)	*Chordeiles minor*	Common nighthawk	P,N
	Strigidae (Owls)	*Asio flammeus*	Short-eared owl	R,N,E
		Bubo virginianus	Great horned owl	P,N
		Megascops asio	Eastern screech owl	P,N
		Strix varia	Barred owl	R,N
	Tytonidae (Owls)	*Tyto alba*	Barn owl	R,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Mammal Species List

Order	Family	Scientific Name	Common Name	Status
Artiodactyla (Even-toed hoofed ungulates)	Cervidae (Caribou, deer, moose)	*Odocoileus virginianus*	White-tailed deer	P,N
Carnivora (Carnivores)	Canidae (Coyotes, dogs, foxes, jackals, wolves)	*Vulpes vulpes*	Red fox	P,N
	Mustelidae (Mustelids)	*Lontra canadensis*	River otter	P,N
	Procyonidae (Procyonids)	*Procyon lotor*	Raccoon	P,N
Chiroptera (Bats)	Vespertilionidae (Vespertilinoid bats)	*Eptesicus fuscus*	Big brown bat	P,N
Didelphimorphia (Marsupials)	Didelphiidae (Opossums)	*Didelphis virginiana*	Opossum	P,N,E
Lagomorpha (Pikas, hares, rabbits)	Leporidae (Hares, rabbits)	*Sylvilagus floridanus*	Eastern cottontail	P,N
Rodentia (Rodents)	Castoridae (Beavers)	*Castor canadensis*	American beaver	P,N
	Muridae (Mice, rats)	*Microtus pinetorum*	Pine vole	R,N
		Ondatra zibethicus	Muskrat	P,N
		Peromyscus leucopus	White-footed mouse	P,N
		Peromyscus maniculatus	Deer mouse	P,N
	Sciuridae (Chipmonks, marmots, squirrels)	*Glaucomys volans*	Southern flying squirrel	P,N
		Sciurus carolinensis	Grey squirrel	P,N
		Tamias striatus	Eastern chipmunk	P,N
Soricomporpha	Soricidae (Shrews)	*Blarina brevicauda*	Short-tailed shrew	R,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Submerged Aquatic Vegetation Species List

Order	Family	Scientific Name	Common Name	Status
Alismatales	Potamogetonaceae (Pondweeds)	*Potamogeton crispus*	Curly pondweed	P,I
		Potamogeton diversifolius	Waterthread	
		Potamogeton epihydrus	Ribbonleaf pondweed	
		Potamogeton perfoliatus	Claspingleaf ponweed, redhead grass	U,N
Halorgales	Halorgaceae (Watermilfoils)	*Myriophyllum spicatum*	Eurasian watermilfoil	P,I
Hydrocharitales	Hydrocharitaceae (Tape-grass, Frog's bit)	*Elodea canadensis*	Elodea, waterweed	R,N
		Hydrilla verticillata	Hydrilla, water thyme	A,I
		Vallisneria americana	American eelgrass, wild celery	P,N
Liliales	Pontederiaceae	*Heteranthera dubia*	Grass-leaf mud-plantain	U,N
Najadales	Najadaceae (Water Nymphs)	*Najas gracillima*	Slender waternymph	
		Najas guadalupensis	Southern naiad	R,N
		Najas minor	Brittle waternymph, spiny naiad	R,I
	Zannichelliaceae (grass wrack)	*Zannichellia palustris*	Horned pondweed	P,N
Nymphaeales	Ceratophyllaceae (Hornworts)	*Ceratophyllum demersum*	Coontail, hornwort	P,N

Status Key: A- Abundant, P- Present, R- Rare, U- Unknown, I- Non-native, N- Native, E- Endangered, T-Threatened, C- Species of Concern

Herbaceous Plant Species List

Order	Family	Scientific Name	Common Name	Status
Alismatales	Alismataceae (Arrowhead, water plantains)	*Alisma triviale*	Water plantain	P,N
		Alisma subcordatum	American water plaintain	
		Sagittaria calycina var. *spongiosa*	Long-lobed arrowhead	P,N
		Sagittaria engelmanniana	Enngelmann's arrowhead	R,N
		Sagittaria latifolia	Arrowhead	A,N
Apiales	Apiaceae	*Cicuta maculata*	Water hemlock	P,N
		Osmorhiza claytoni	Sweet cicely	
		Sanicula canadensis	Canadian black snakeroot	
		Sium suave	Water parsnip	P,N
Arales	Acoraceae	*Acorus americanus*	Sweetflag	A,N

Order	Family	Scientific Name	Common Name	Status
	Araceae	*Arisaema triphyllium*	Jack-in-the-pulpit	
		Orontium aquaticum	Goldenclub	U,N
		Peltandra virginica	Arrow arum	P,N,E
		Symplocarpus foetidus	Skunk cabbage	P,N
Aristolochiales	Aristolochiaceae (Birthworts)	*Asarum canadense*	Canadian wild ginger	
Asparagales	Iridaceae	*Iris pseudacorus*	Yellow iris	
		Iris versicolor	Blue flag	P,N
	Orchidaceae (Orchids)	*Cypripedium acaule*	Pink Lady's Slipper	P,N
		Goodyera pubescens	Downy rattlesnake plantain	
Asterales	Asteraceae (Sunflowers)	*Ambrosia trifida*	Great ragweed	P,N
		Bidens laevis	Bur-marigold, smooth beggartick	U,N
		Bidens trichosperma	Tickseed sunflower	
		Eupatorium perfoliatum	Boneset	
		Eutrochium purpureum	Sweet joe pye weed	P,N
		Eutrochium fistulosum	Hollow joe pye weed, trumpetweed	P,N
		Helenium autumnale	Sneezeweed	P,N
		Helianthus tuberosus	Jerusalem artichoke	U,N
		Mikania scandens	Climbing hempweed	P,N
		Rudbeckia laciniata	Green-headed coneflower	P,N
		Solidago caesia	Blue-stemmed goldenrod	
		Solidago gigantea	Giant goldenrod	
		Symphyotrichum lanceolatum var. *lanceolatum*	White panicle aster	P,N
		Symphytotrichum novi-belgii	New York aster	
		Symphyotrichum pilosum	Heath aster	
		Taraxacum officinale	Dandelion	P,I
		Vernonia noveboracensis	New York ironweed	P,N
Campanulales	Campanulaceae (Harebells)	*Lobelia cardinalis*	Cardinal flower	P,N
		Lobelia siphilitica	Great blue lobelia	
Capparales	Brassicaceae (Mustards)	*Alliaria petiolata*	Garlic mustard	A,I
		Cardamine bulbosa	Spring cress	U,N
		Cardamine concatenata	Cutleaf toothwort	
		Thlaspi arvense	Field pennycress	
Caryophyllales	Amaranthaceae (Pigweeds)	*Amaranthus cannabinus*	Water hemp, tidalmarsh amaranth	P,N
	Caryophyllaceae (Pinks)	*Stellaria longifolia*	Longleaf stitchwort	
		Stellaria media	Chickweed	
	Phytolaccaceae (Pokeweeds)	*Phytolacca Americana*	Pokeweed	
	Portulacaceae (Purslanes)	*Claytonia virginica*	Spring beauty	U,N
Celastrales	Celastraceae (Bittersweets)	*Celastrus orbiculatus*	Oriental bittersweet	A,I

Order	Family	Scientific Name	Common Name	Status
Commelinales	Commelinaceae (Spiderworts)	*Commelina* spp.	Dayflower	P,N
Cyperales	Cyperaceae (Sedges)	*Agrostis gigantea*	Water bentgrass	
		Bolboschoenus fluviatilis	River bulrush	P,N
		Bolboschoenus maritimus	Cosmopolitan bulrush	
		Carex albolutescens	Greenwhite sedge	P,N
		Carex comosa	Longhair sedge	P,N
		Carex crinita	Fringed sedge	
		Carex lurida	Shallow sedge	
		Carex scoparia	Broomsedge	
		Carex spp.	Sedge	
		Carex stipata	Owlfruit sedge	
		Carex vulpinoidea	Fox sedge	
		Cyperus strigosus	Umbrella sedge, strawcolor flatsedge	P,N
		Dulichium arundinaceum	Three-way sedge	P,N
		Eleocharis ambigens	Spikerush	
		Eleocharis obtusa	Blunt spikerush	
		Eleocharis spp.	Spikesedge	
		Schoenoplectus pungens	Three-square	P,N
		Schoenoplectus tabernaemontani	Softstem bulrush	
		Scirpus atrovirens	Dark green bulrush	
		Scirpus cyperinus	Woolgrass	P,N
	Poaceae (Grasses)	*Agrostis gigantea*	Creeping bentgrass	U,I
		Andropogon virginicus	Broomsedge	
		Bromus japonicus	Japanese bromegrass	
		Cinna arundinacea	Reedgrass	
		Dichanthelium clandestinum	Deertongue grass	P,N
		Dichanthelium spp.	Panic grass, rosette grass	P,N,E
		Echinochloa muricata	Rough barnyard grass	
		Elymus virginicus	Virginia ryegrass, Virginia wildrye	P,N
		Festuca trachyphylla	Sheep fescue	
		Glyceria striata	Fowl manna grass	
		Leersia oryzoides	Rice cutgrass	P,N
		Leersia virginica	White grass	
		Microstegium vimineum	Japanese stiltgrass	A,I
		Phalaris arundinacea	Reed canarygrass	
		Phragmites australis	Common reed	P,N,C
		Phyllostachys sp.	Bamboo	
		Poa trivialis	Rough bluegrass	
		Zizania aquatica	Wild rice	P,N

Order	Family	Scientific Name	Common Name	Status
Dipsacales	Caprifoliaceae (Honeysuckles)	*Lonicera japonica*	Japanese honeysuckle	A,I
		Sambucus nigra	European black elderberry	U,N
Equisetales	Equisetaceae (Horsetails)	*Equisetum sp.*	Scouring rush	
Fabales	Fabaceae	*Amphicarpa bracteata*	Hog-peanut	
		Apios americana	Groundnut	P,N
		Senna hebecarpa	America senna	
Gentianales	Asclepiadaceae (Milkweeds)	*Asclepias incarnata*	Swamp milkweed	P,N
Geraniales	Balsaminaceae (Touch-me-nots)	*Impatiens capensis*	Jewelweed	P,N
		Impatiens pallida	Pale jewelweed	
Juncales	Juncaceae (Rushes)	*Juncus canadensis*	Canadian rush	
		Juncus effusus	Common rush	P,N
Lamiales	Boraginaceae (Borages)	*Myosotis laxa*	Bay forget-me-not	
	Lamiaceae (Mints)	*Glechoma hederacea*	Ground ivy	
		Lamium pupureum	Purple deadnettle	
		Lycopus uniflorus	Northern bugleweed	
		Mentha arvensis	Wild mint	P,N
		Mentha spicata	Spearmint	
	Verbenaceae (Verbenas)	*Verbena hastate*	Blue vervain	
Liliales	Discoreaceae	*Dioscorea villosa*	Wild yam	P,N
	Liliaceae	*Allium vineale*	Wild garlic	
		Erythronium umbilicatum	Trout lily	P,N
		Hemerocallis fulva	Orange day lily	P,I
		Lilium superbum	Turk's cap lily	P,I
		Polygonatum biflorum var. *commutatum*	King Solomon’s seal	
	Pontederiaceae	*Pontederia cordata*	Pickerelweed	P,N
Lycopodiales	Lycopodiaceae (Club mosses)	*Lycopodium complanatum*	Ground pine	
Malvales	Malvaceae (Mallows)	*Hibiscus moscheutos*	Marsh hibiscus, marshmallow	P,N
Myrtales	Lythraceae (Loosestrife)	*Lythrum lineare*	Wand lythrum	
	Onagraceae (Evening primroses)	*Circaea* sp.	Enchanter’s nightshade	
Nymphaeales	Nymphaeaceae (Water lilies)	*Nuphar lutea ssp. advena*	Spatterdock	A,N
Papaverales	Fumariaceae (Fumitory)	*Dicentra cucullaria*	Dutchman’s breeches	
Piperales	Saururaceae (Lizard tails)	*Saururus cernuus*	Lizard’s tail	
Polygonales	Dennstaedtiaceae	*Dennstaedtia punctilobula*	Eastern hay-scented fern	
	Polygonaceae (Knotweeds)	*Polygonum amphibium* var. *emersum*	Swamp smartweed	
		Polygonum arifolium	Halberdleaf tearthumb	P,N

Order	Family	Scientific Name	Common Name	Status
		Polygonum hydropiperoides	Mild water pepper	
		Polygonum perfoliatum	Asian tearthumb	
		Polygonum punctatum	Dotted smartweed	
		Polygonum sagittatum	Arrow-leaf tearthumb	P,N
		Polygonum scandens	Climbing false buckwheat	
		Polygonum spp.	Smartweed	
		Polygonum virginianum	Jumpseed, Virginia smartweed	
Polypodiales	Dryopteridaceae	*Onoclea sensibilis*	Sensitive fern	
Primulales	Primulaceae (Primroses)	*Lysimachia ciliata*	Fringed loosestrife	P,N
		Lysimachia nummularia	Creeping Jenny, moneywort	P,I
		Lysimachia quadrifolia	Whorled loosestrife	U,N
		Lythrum salicaria	Purple losestrife	R,I
Ranunculales	Berberidaceae (Bayberries)	*Podophyllum peltatum*	May apple	
	Ranunculaceae (Buttercups)	*Clematis virginiana*	Virgin's bower	
		Ranunculus abortivus	Small-flower crowfoot	
		Ranunculus hispidus	Bristly buttercup	P,N
		Ranunculus hispidus var. *nitidus*	Swamp buttercup	
		Thalictrum pubescens	Tall meadow rue	
		Thalictrum thalictroides	Rue anemone	
Rosales	Rosaceae (Roses)	*Agrimonia parviflora*	Harvest lice	
		Duchesnea indica	Indian strawberry	
		Fragaria vesca	Woodland strawberry	
		Geum canadense	White avens	
Rubiales	Rubiaceae (Madders)	*Galium aparine*	Cleavers	
		Galium palustre	Marsh bedstraw	P,N
		Galium obtusum	Bluntleaf bedstraw	
		Galium spp.	Bedstraw	
		Galium tinctorium	Stiff marsh bedstraw	P,N
Sapindales	Anacardiaceae (Cashews)	*Toxicodendron radicans*	Poison ivy	P,N
Scrophulariales	Acanthaceae (Acanthus)	*Justicia americana*	American water-willow	
	Scrophulariaceae (Figworts)	*Chelone* spp.	Turtlehead	U,T
		Chelone galabra	White turtlehead	
Solanales	Convolvulaceae (Morning glories)	*Calystegia sepium*	Hedge bindweed	P,N
	Cuscutaceae (Dodders)	*Cuscuta gronovii*	Scaldweed	
		Cuscuta polygonorum	Smartweed dodder	P,N,E
Theales	Clusiaceae	*Hypericum mutilum*	Dwarf St. Johnswort	
		Triadenum virginicum	Marsh St. Johnswort	
Typhales	Sparaganiaceae	*Sparganium americanum*	American bur-reed	P,N

Order	Family	Scientific Name	Common Name	Status
	Typhaceae	*Typha angustifolia*	Narrow-leaf cattail	P,I
		Typha latifolia	Broad-leaf cattail	P,N
Urticales	Cannabaceae (Hemp)	*Humulus japonicus*	Japanese hops	P,I
	Urticaceae (Nettles)	*Boehmeria cylindrica*	False nettle	P,N
		Pilea pumila	Clearweed	P,N
		Urtica dioica	Stinging nettle	
Violales	Violaceae (Violets)	*Viola pubescens* var. *pubescens*	Smooth yellow violet	
		Viola sororia	Common blue violet	P,N

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Woody Plant Species List

Order	Family	Scientific Name	Common Name	Status
Celastrales	Aquifoliaceae (Hollies)	*Ilex opaca*	American holly	P,N
	Celastraceae (Bittersweets)	*Celastrus orbiculatus*	Asian bittersweet	P,I
Cornales	Cornaceae (Dogwoods)	*Cornus amomum*	Silky dogwood	P,N
		Cornus florida	Flowering dogwood	P,N
		Cornus sericea ssp. sericea	Redosier dogwood	
Dipsacales	Caprifoliaceae (Honeysuckles)	*Lonicera japonica*	Japanese honeysuckle	P,I
		Sambucus nigra ssp. *canadensis*	Common elderberry	P,N
		Viburnum dentatum	Southern arrowwood	P,N
		Viburnum nudum	Possumhaw	P,N
Ericales	Clethraceae (Pepperbushes)	*Clethra alnifolia*	Sweet pepperbush	P,N
	Ericaceae (Heaths)	*Kalmia latifolia*	Mountain laurel	A,N
		Vaccinium angustifolium	Lowbush blueberry	U,N
		Vaccinium corymbosum	Highbush blueberry	P,N
	Monotropaceae (Indian pipes)	*Monotropa uniflora*	Indianpipe	U,N
Fabales (Peas)	Fabaceae	*Robinia pseudoacacia*	Black locust	P,N
Fagales (Birches and beeches)	Betulaceae (Alders, birches)	*Alnus serrulata*	Smooth alder	P,N
		Betula nigra	River birch	P,N
		Carpinus caroliniana	American hornbeam	P,N
	Fagaceae (Beeches)	*Fagus grandifolia*	American beech	P,N
		Quercus coccinea	Scarlet oak	P,N
		Quercus falcata	Southern red oak	P,N
		Quercus palustris	Pin oak	P,N

Order	Family	Scientific Name	Common Name	Status
		Quercus phellos	Willow oak	P,N
		Quercus prinus	Chestnut oak	P,N
		Quercus rubra	Red oak	P,N
Hamamelidiae	Hamamelidaceae (Witch hazels)	*Hamamelis virginiana*	Witch hazel	U,N
		Liquidambar styraciflua	Sweetgum	P,N
		Nyssa sylvatica	Black gum	P,N
	Platanaceae (Plane trees)	*Platanus occidentalis*	Sycamore	P,N
Juglandales	Juglandaceae (Walnuts)	*Carya cordiformis*	Bitternut hickory	P,N
Laurales	Lauraceae (Laurels)	*Lindera benzoin*	Spicebush	P,N
		Sassafras albidum	Sassafras	P,N
Liliales	Smilacaceae	*Smilax* spp.	Greenbrier	P,N
Magnoliales	Annonaceae (Custard apples)	*Asimina triloba*	Paw paw	R,N
	Magnoliaceae (Magnolias)	*Liriodendron tulipifera*	Tulip poplar	P,N
		Magnolia virginia	Sweetbay magnolia	U,N
Pinales	Pinaceae (Pines)	*Pinus rigida*	Pitch pine	P,N
		Pinus virginiana	Virginia pine	U,N
Rhamnales	Vitaceae (Grapes)	*Parthenocissus quinquefolia*	Virginia creeper	P,N
		Vitis spp.	Grape	
		Vitis vinifera	Wild grape	P,N
Rosales	Rosaceae (Roses)	*Amelanchier* spp.	Serviceberry	P,N
		Prunus serotina	Black cherry	P,N
		Rosa spp.	Wild rose	P,N
		Rosa multiflora	Mutliflora rose	A,I
Rubiales	Rubiaceae (Madders)	*Cephalanthus occidentalis*	Buttonbush	P,N
Salicales	Salicaceae (Willows)	*Salix nigra*	Black willow	P,N
Sapindales	Aceraceae (Maples)	*Acer negundo*	Box elder	P,N
		Acer rubrum	Red maple	P,N
		Acer saccharinum	Silver maple	P,N
	Anacardiaceae (Cashews)	*Toxicodendron radicans*	Poison ivy	P,N
Scrophulariales	Oleaceae (Olives)	*Fraxinus pennsylvanica*	Green Ash	P,N
Urticales	Moraceae (Mulberries)	*Morus alba*	White mulberry	R,I

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APPENDIX II

Partial list of species found in Monie Bay, Chesapeake Bay National Estuarine Research Reserve. Species are organized by order, family, scientific name and common name.

Invertebrate Species List

Order	Family	Scientific Name	Common Name
Aciculata	Glyceridae	*Glycera dibranchiata*	
	Goniadidae	*Glycinde solitaria*	
	Nephtyidae	*Nephtys* spp.	
	Nereididae	*Neanthes* spp.	
		Nereis spp.	
		Platynereis dumerilii	
Amphipoda (Amphipods)	Aoridae	*Leptocheirus plumulosus*	
	Corophiidae	*Apocorophium* spp.	
	Gammaridae	*Gammarus* spp.	
Archaeopulmonata	Ellobiidae	*Melampus bidentatus*	Eastern melampus
Canalipalpata	Spionidae	*Marenzelleria* spp.	
		Marenzelleria viridis	
Coleoptera (Beetles)	Elmidae (Riffle beetles)	*Optioserves* spp.	
		Stenelmis spp.	
Decapoda (Crabs, crayfishes, lobsters, prawns, and shrimp)	Ocypodidae (Fiddler crabs and ghost crabs)	*Uca* spp.	Fiddler crab
		Ucides spp.	
	Palaemonidae	*Palaemonetes* spp.	
		Palaemonetes pugio	Daggerblade grass shrimp
		Palaemonetes vulgaris	Common grass shrimp
		Rhithropanopeus harrisii	Estuarine mud crab
	Portunidae (Swimming crabs)	*Callinectes sapidus*	Blue crab
Diptera (Gnats, mosquitoes, and true flies)	Ceratopogonidae (Biting midges, no-see-ums, punkies)		
	Chironomidae (Midges)	*Chironomus* spp.	
		Dicrotendipes spp.	
		Paraphaenocladius spp.	
Enteropnuesta (Acorn worms)	Harrimaniidae	*Saccoglossus kowalevskii*	

Order	Family	Scientific Name	Common Name
Haplotaxida	Enchytraeidae		
	Tubificidae	*Peloscolex heterochaetus*	
		Tubificoides brownae	
Isopoda (Isopods, pillbugs, and sowbugs)	Anthuridae	*Cyanthura* spp.	
		Cyathura polita	Slender isopod
	Idoteidae	*Edotia* spp.	
Myoida	Myidae	*Mya arenaria*	Softshell clam
Neotanenioglossa	Littorinidae	*Littorina irrorata*	Marsh periwinkle
Ostreoida	Ostreidae	*Crassostrea virginica*	Eastern oyster
Veneroida	Tellinidae	*Macoma balthica*	Baltic macoma clam
		Tellina agilis	Northern dwarf tellin
	Veneroidae	*Gemma gemma*	Amethyst gemclam

Amphibian Species List

Order	Family	Scientific Name	Common Name
Anura (Frogs and toads)	Ranidae (Ranid frogs, riparian frogs, and true frogs)	*Lithobates catesbeianus*	American bullfrog
		Lithobates clamitans melanota	Northern green frog
		Lithobates palustris	Pickerel frog

Reptile Species List

Order	Family	Scientific Name	Common Name
Testudines (Terrapins, tortoises, and turtles)	Emydidae (Emydid turtles, pond turtles, terrapins)	*Malaclemys terrapin terrapin*	Northern diamondback terrapin
	Kinosternidae (Mud turtles and musk turtles)	*Kinosternon subrubrum*	Eastern mud turtle

Fish Species List

Order	Family	Scientific Name	Common Name
Anguilliformes (Eels)	Anguillidae (Freshwater eels)	*Anguilla rostrata*	American eel
Atheriniformes (Silversides)	Atherinopsidae (New World silversides)	*Menidia menidia*	Atlantic silverside
Clupeiformes (Anchovies and herrings)	Clupeidae (Herrings, menhadens, sardines, and shads)	*Brevoortia tyrannus*	Atlantic menhaden
	Engraulidae (Anchovies)	*Anchoa hepsetus*	Striped anchovy
		Anchoa mitchilli	Bay anchovy
Cypriniformes (Cyprins, minnows, and suckers)	Cyprinidae (Carps and minnows)	*Cyprinus carpio*	Common carp
Cyprinodontiformes (Cyprinodontiforms, cyprinodonts, and killifishes)	Cyprinodontidae (Cyprinodontids, killifishes, pupfishes, and toothcarps)	*Cyprinodon variegatus*	Sheepshead minnow
	Fundulidae (Killifishes and topminnows)	*Fundulus diaphanus*	Banded killifish
		Fundulus heteroclutius	Mummichog
	Poeciliidae (Livebearers)	*Gambusia affinis*	Eastern mosquitofish
Esociformes (Mudminnows and pikes)	Esocidae (Pickerels and pikes)	*Esox americanus*	Redfin pickerel
	Umbridae (Mudminnows)	*Umbra pygmaea*	Eastern mudminnow
Percifomes (Perch-like fishes)	Centrarchidae (Sunfishes)	*Enneacanthus obesus*	Banded sunfish
		Lepomis gibbosus	Pumpkinseed
	Gobiidae (Gobies)	*Gobiosoma bosc*	Naked goby
	Moronidae (Temperate basses)	*Morone americana*	White perch
		Morone saxatilis	Striped bass
	Sciaenidae (Croakers and drums)	*Leiostomus xanthurus*	Spot
		Bairdiella chrysoura	Silver perch
Pleuronectiformes (Flatfishes, flounders, and soles)	Achiridae (American soles)	*Trinectes maculates*	Hogchoker
Siluriformes (Catfishes)	Ictaluridae (Bullhead catfishes and North American freshwater catfishes)	*Ameiurus catus*	White catfish

Bird Species List

Order	Family	Scientific Name	Common Name
Anseriformes (Ducks, geese, swans, and waterfowl)	Anatidae (Ducks, geese, and swans)	*Aix sponsa*	Wood duck
		Anas platyrhynchos Linnaeus	Mallard
		Anas rubripes Brewster	Black duck
		Anas crecca Linnaeus	Green winged teal
		Branta canadensis	Canada goose
		Cygnus olor	Mute swan
		Lophodytes cucullatus	Hooded merganser
Ciconiiformes (Auks, ibises, penguins, and storks)	Accipitridae (Hawks and kites)	*Circus cyaneus*	Northern harrier
		Haliaeetus leucocephalus	Bald eagle
		Pandion haliaetus	Osprey
	Ardeidae (Bitterns, egrets, and herons)	*Ardea alba*	Great egret
		Ardea herodias	Great blue heron
		Botaurus lentiginosus	American bittern
		Butorides virescens	Green heron
		Egretta thula	Snowy egret
		Ixobrychus exilis	Least bittern
	Charadriidae (Oystercatchers, plovers, and stilts)	*Charadrius semipalmatus*	Semipalmated plover
	Ciconiidae (American vultures)	*Cathartes aura*	Turkey vulture
		Coragyps atratus	Black vulture
	Falconidae (Falcons)	*Falco peregrinus*	Peregrine falcon
	Laridae (gulls, and terns)	*Larus argentatus*	Herring gull
		Larus artricilla	Laughing gull
		Sterna antillarum	Least tern
	Podicipedidae (Grebes)	*Podilymbus podiceps*	Pied billed grebe
	Scolopacidae (Sandpipers)	*Calidris minutilla*	Least sandpiper
		Catoptrophorus semipalmatus	Willet
	Threskiornithidae (Ibises and spoonbills)	*Plegadis falcinellus*	Glossy ibis
Columbiformes (Doves and pigeons)	Columbidae (Doves and pigeons)	*Zenaida macroura*	Mourning dove
Cuculiformes (Cukoos)	Cuculidae (Anis, cuckoos, and roadrunners)	*Coccyzus americanus*	Yellow-billed cuckoo

Order	Family	Scientific Name	Common Name
Galliformes (Gallinaceous birds)	Phasianidae (Grouse, patridges, pheasants, quails, and turkeys)	*Meleagris gallopavo*	Wild turkey
Gruiformes (Cranes and rails)	Rallidae (Coots, rails, and waterhens)	*Gallinula chloropus*	Common moorhen
		Gallinula chloropus guami Hartert	Common gallinule
		Rallus limicola	Virginia rail
		Rallus longirostris	Clapper rail
Passeriformes (Perching birds)	Cardinalidae (Cardinals, grosbeaks, and saltators)	*Cardinalis cardinalis*	Northern cardinal
	Corvidae (Crows, jays and magpies)	*Corvus brachyrhynchos*	American crow
	Emberizidae (American sparrows, buntings, emberizid finches, New World sparrows, and towhees)	*Ammodramus maritimus*	Seaside sparrow
	Fringillidae (Finches, Hawaiian honeycreeprs, and Old World finches)	*Carpodacus mexicanus*	House finch
	Hirundinidae (Swallows)	*Hirundo rustica*	Barn swallow
		Progne subis	Purple martin
		Stelgidopteryx serripennis	Northern rough-winged swallow
		Tachycineta bicolor	Tree swallow
	Icteridae (American blackbirds, New World blackbirds, and orioles)	*Agelaius phoeniceus*	Red-winged blackbird
		Euphagus carolinus	Rusty blackbird
		Quiscalus major	Boat-tailed grackle
		Quiscalus quiscula	Common grackle
	Mimidae (Mockingbirds and thrashers)	*Mimus polyglottos*	Northern mockingbird
	Paridae (Chickadees and titmice)	*Baeolophus bicolor*	Tufted titmouse
	Parulidae (New World Warblers and wood-warblers)	*Dendroica discolor*	Prairie warbler
		Geothlypis trichas	Common yellowthroat
	Sturnidae (Starlings)	*Sturnus vulgaris*	European starling
	Troglodytidae (Wrens)	*Cistothorus palustris*	Marsh wren
		Cistothorus platensis	Sedge wren
		Thryothorus ludovicianus	Carolina wren
		Troglodytes aedon	House wren
	Tyrannidae (Tyrant flycatchers)	*Contopus virens*	Eastern wood-pewee
		Myiarchus crinitus	Great crested flycatcher
		Tyrannus tyrannus	Eastern kingbird
Piciformes (Woodpeckers)	Picidae (Woodpeckers and wrynecks)	*Colaptes auratus*	Northern flicker

Order	Family	Scientific Name	Common Name
		Melanerpes carolinus	Red-bellied woodpecker
Strigiformes (Goatsuckers and owls)	Caprimulgidae (Nightjars)	*Caprimulgus carolinensis*	Chuck-will's-widow
	Strigidae (Owls)	*Bubo virginianus*	Great horned owl
	Tytonidae (Barn owls)	*Tyto alba*	Barn owl

Mammal Species List

Order	Family	Scientific Name	Common Name
Rodentia (Rodents)	Echimyidae	*Myocastor coypus*	Nutria

Submerged Aquatic Vegetation Species List

Order	Family	Scientific Name	Common Name
Alismatales	Ruppiaceae (Ditch grass)	*Ruppia maritima*	Widgeon grass

Herbaceous (Wetland) Plant Species List

Order	Family	Scientific Name	Common Name
Apiales	Apiaceae	*Ptilimnium capillaceum*	Threadleaf mockbishopweed
Asterales	Asteraceae (Sunflowers)	*Cyclachaena xanthifolia*	Marshelder
		Iva frutescens	Jesuit's bark
		Symphyotrichum tenuifolium	Saline aster
		Pluchea odorata var. odorata	Marsh fleabane
		Solidago sempervirens	Seaside goldenroad
		Baccharis halimifolia	Groundsel bush
Caryophyllales	Amaranthaceae (Pigweed)	*Amaranthus cannabinus*	Tidal marsh amaranth
	Chenopodiaceae (Goosefoot)	*Atriplex patula*	Spear saltbush
Cyperales	Poaceae (Grasses)	*Spartina alterniflora*	Smooth cordgrass
		Spartina patens	Salt cordgrass

Order	Family	Scientific Name	Common Name
		Spartina cynosuroides	Big cordgrass
		Phragmites australis	Common reed
		Distichlis spicata	Marsh spikegrass
	Cyperaceae (Sedges)	*Schoenoplectus pungens var. pungens*	Common threesquare
		Eleocharis acicularis	Needlerush
		Eleocharis parvula	Dwarf spikerush
		Schoenoplectus americanus	American bulrush
		Schoenoplectus robustus	Sturdy bulrush
Juncales	Juncaceae (Rushes)	*Juncus roemerianus*	Needlegrass rush
		Juncus gerardi	Saltmeadow rush
Malvales	Malvaceae (Mallows)	*Hibiscus moscheutos*	Swamp rosemallow
		Althaea officinalis	Common marsh-mallow
Polygonales	Polygonaceae (Knotweed)	*Polygonum punctatum*	Dotted smartweed
		Rumex verticillatus	Swamp dock
Primulales	Primulaceae (Primroses)	*Samolus valerandi ssp. parviflorus*	Seaside brookweed
Sapindales	Anacardiaceae (Cashews)	*Toxicodendron radicans*	Poison ivy

Woody Plant Species List

Order	Family	Scientific Name	Common Name
Liliales	Smilacaceae	*Smilax ecirrata*	Greenbriar
Myricales	Myricaceae (Sweet gale)	*Morella cerifera*	Wax myrtle
Pinales	Pinaceae	*Pinus taeda*	Loblolly pine