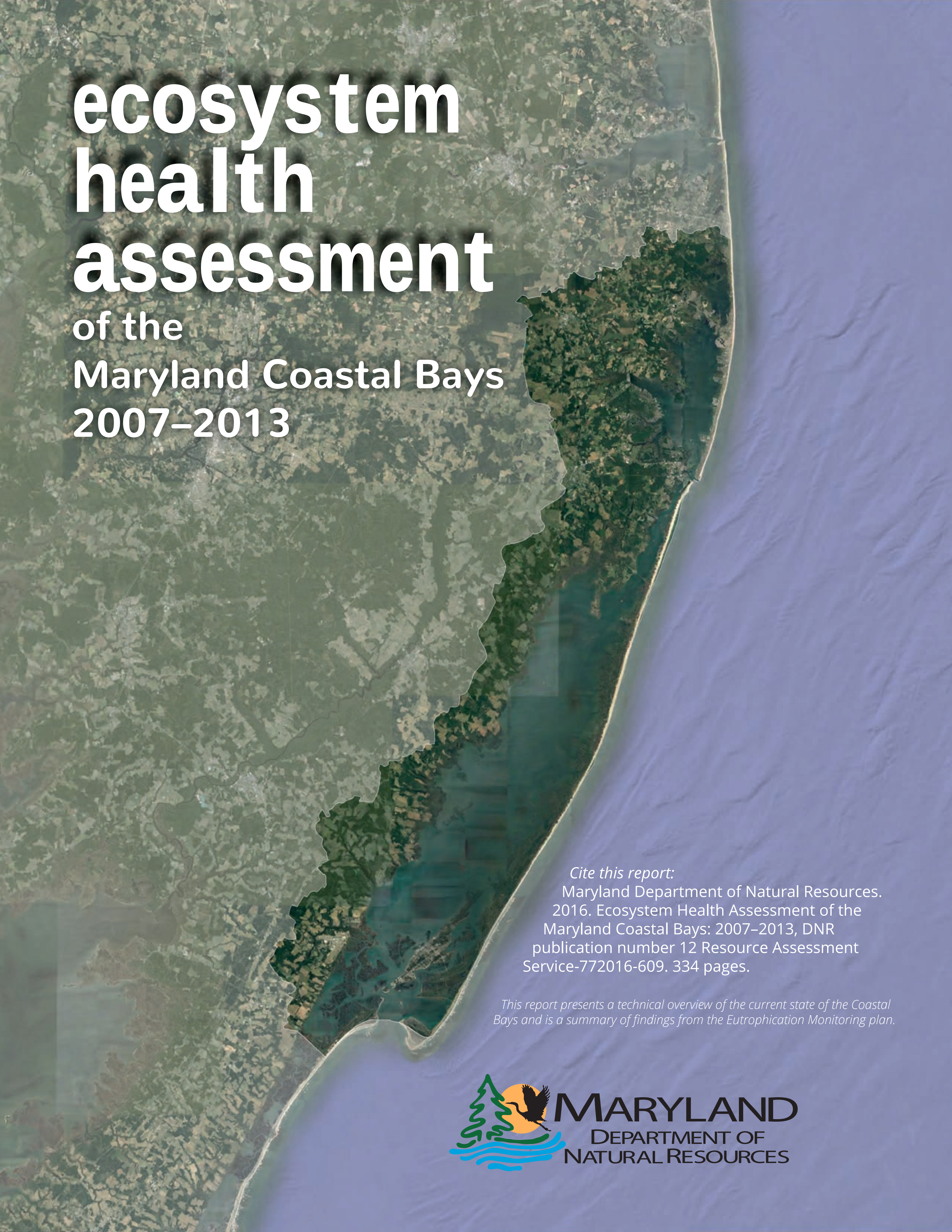

ecosystem health assessment

of the Maryland Coastal Bays 2007–2013

Cite this report:
Maryland Department of Natural Resources. 2016. Ecosystem Health Assessment of the Maryland Coastal Bays: 2007–2013, DNR publication number 12 Resource Assessment Service-772016-609. 334 pages.

This report presents a technical overview of the current state of the Coastal Bays and is a summary of findings from the Eutrophication Monitoring plan.

Maryland
Department of
Natural Resources

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Chapter 1.1

Ecosystem health assessment: Monitoring Maryland's Coastal Bays

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Introduction
The Maryland Coastal Bays estuary is one of 28 estuaries recognized through the U.S. Environmental Protection Agency's (EPA) National Estuary Program. The Coastal Bays are defined as shallow lagoons. Lagoons are bay systems that are characterized by being located behind barrier islands, having shallow depths, high salinities and limited flushing. These natural characteristics drive ecosystem processes, but these processes are affected by human (anthropogenic) influences.

This report uses environmental indicators to measure the health of the bays and provides an assessment of progress made toward implementing the priority actions of the Comprehensive Conservation and Management Plan (CCMP) created in conjunction with the EPA designation. **This report attempts to capture the major elements of the bays health that reflect the current perceptions of scientists and managers as to what constitutes the State of the Bays Health.** It contains many of the traditional measures for assessing aquatic ecosystem health.

The Aquatic Ecosystem Health Monitoring Plan was developed to help determine the effectiveness of management actions taken as part of the Maryland Coastal Bays National Estuary Programs' Comprehensive Conservation Management Plan (CCMP) (Maryland Coastal Bays Program 1999). Actions in the management plan address five priority problems: degraded water quality, loss of habitats, changes in living resources, unsustainable growth and development, and poorly planned recreational use of the bays. Degraded water quality, due to nutrient and sediment enrichment, was identified as the most pressing environmental problem facing Maryland's Coastal Bays. The Eutrophication Monitoring Plan was designed to specifically track the implementation of management actions and monitor changes in nutrient/sediment loading and subsequent responses to the ecosystem (e.g. impacts to general water quality, habitat and living resources).

One of the long-term goals of the Maryland Coastal Bays Program (MCBP) is to help identify and track a set of **regional environmental indicators and related threshold levels** and produce a "State of the Coastal Bays" report. The aquatic environmental indicators developed by the MCBP Scientific and Technical Advisory Committee (STAC) are used in this report to assess the health of the bays in addition to some new draft indicators (MCBP 2002) (Table 1.1.1). Environmental indicators are used to describe the status and trends of our natural resources, environmental health and ecological condition. They help raise awareness about important issues, can inform environmental policy decisions and serve as a tool for evaluating the effectiveness of management actions. Environmental indicators are similar to many of the economic and social indicators that are ingrained into our culture, such as the Dow Jones Industrial Average. Just as the Dow gives investors a general picture of the state of the market, environmental indicators give scientists and managers a picture of the state of our ecosystems.

A variety of indicators and thresholds were used to assess estuarine health (summary table of indicators and thresholds used in Table 1.1.1). Thresholds were approved by STAC. Maryland Department of Natural Resources (DNR) scientists have worked with MCBP, University of Maryland and other researchers to evaluate the Coastal Bays monitoring data collected since 2001.

This report is intended to supplement other publications, such as the MCBP Progress Report and the University of Maryland Center for Environmental Science (UMCES), Integrated Analyses Network (IAN) Report Card. The MCBP Progress Report summarizes the management actions taken to date on each of the priority problems listed above. This report will serve to inform managers on the effectiveness of these actions. The IAN Report Card will be produced this year and will provide a "snapshot" of the Coastal Bays water quality based on intensive sampling over a few days or weeks. The "State of the Bays" report is intended to provide comprehensive coverage over a three-year period. This report will also inform and supplement current efforts by the Maryland Department of the Environment (MDE) and the Worcester County Department of Planning to develop and implement Total Maximum Daily Load (TMDL) regulations and Watershed Restoration Action Strategy (WRAS) plans, respectively.

For this report, the Coastal Bays, located in Worcester County behind Ocean City and Assateague Island, have been divided into six segments in which conditions are reported. The segments include Assawoman Bay, Isle of Wight Bay, St. Martin River, Sinepuxent Bay, Newport Bay and Chincoteague Bay (Figure 1.1.1).

Table 1.1.1 Summary of Indicator and thresholds

Aquatic Ecosystem Component	Indicator	Threshold	Monitoring Frequency
Stream Health	Stream nitrate	Less than 1 mg/L	Highly varied
	Stream bottom-dwelling animal index1	Less than or equal to 2.8	Annually
	Stream bottom-dwelling animal index2	Less than or equal to_ 4	Every 5 years
	Freshwater fish index	Greater than or equal to_ 4	Every 5 years
Water Quality	Total Nitrogen	No more than 0.65 mg/L for seagrass growth; No more than 1 mg/L as set by STAC*	Monthly
	Total Phosphorus	No more than 0.037 mg/L for seagrass growth; No more than 0.01 mg/L as set by STAC*	Monthly
	Chlorophyll *a*	No more than 15 micrograms/L to prevent low dissolved oxygen; No more than 50 micrograms/L as set by STAC*	Monthly, as well as continuous monitoring and water quality mapping (the latter two measure total chlorophyll)
	Dissolved Oxygen	No less than 5 mg/L to prevent effects on aquatic life; No less than 3 mg/L as set by STAC*	Monthly, as well as continuous monitoring and water quality mapping
	Water Quality Index	Greater than 0.6	Calculated by combining values from all water quality indicators
Harmful Algae	Harmful Algae Blooms	Species specific thresholds	As needed, when water quality indicates algae at high levels
Habitat	Seagrass	Goal acreage in development	Annual survey
	Macroalgae	None	Not routinely monitored
	Shoreline	Percent natural shoreline	Not routinely monitored
	Wetlands	No net loss	Not monitored directly
Living Resources	Phytoplankton	None	Monthly – weekly
	Fish	No decreasing trend in forage fish index	Monthly Trawl: April – Oct Seine: June and Sept.
	Fish kills	none	As needed
	Shellfish (clams, scallops, oysters)	None	Clams – annual survey
	Blue crabs	None	Monthly with fish survey
	Bottom dwelling animals	Federally-mandated index values	Annually 2000 - 2003

Monitoring

Many agencies participate in monitoring the Coastal Bays ecosystem (see Table 1.1.2). Monitoring data is used to characterize water quality, habitat and living resource conditions, providing an essential component to identifying and implementing management actions to address problem areas.

Table 1.1.2 Summary of monitoring efforts in the Coastal Bays.

Aquatic Ecosystem Component	**Criteria**	**Monitoring group***
Stream Health	Stream nitrate	MD DNR- watershed restoration service (WRS); U.S. Geologic Survey (USGS), MD DNR- Monitoring and non-tidal assessment (MANTA)
	Stream benthic index1 Stream benthic index2	MD DNR- MANTA MD DNR- Maryland Biological Stream Survey (MBSS)
	Freshwater fish index	DNR- MBSS
Water Quality	Total Nitrogen	ASIS MD DNR – Tidewater Ecosystem Assessment (TEA)
	Total Phosphorus	ASIS MD DNR – TEA
	Chlorophyll *a*	ASIS MD DNR – TEA MCBP
	Dissolved Oxygen	Assateague Island (ASIS) National Park Service MD DNR – TEA
	Benthic Chlorophyll	MD DNR-TEA
	Water Quality Index	DNR
Harmful Algae	Brown Tide	MD DNR – TEA ASIS
	Harmful Algae Blooms	MD DNR - TEA
Habitat	Seagrass	Virginia Institute of Marine Science (VIMS)
	Submerged aquatic vegetation (SAV) Index	MD DNR- TEA
	SAV water clarity	MD DNR- TEA
	Macroalgae	MD DNR - TEA
	Wetlands	MD DNR-WRS Maryland Department of the Environment (MDE) U.S. Army Corps of Engineers
	Fish	MD DNR – coastal fisheries
	Fishkills	MDE
	Shellfish (clams, scallops, oysters)	MD DNR – coastal fisheries
	Benthic Index	MD DNR - TEA
	Bluecrabs	MD DNR – coastal fisheries
	Horseshoe crab	MD DNR – coastal fisheries MCBP
	Piping Plove	ASIS
	Waterbirds	MD DNR – Wildlife and Heritage

* DNR-Maryland Department of Natural Resources (the following are DNR divisions and programs): WRS-Watershed Restoration Service; MANTA-Monitoring and Non-Tidal Assessment; MBSS-Maryland Biological Stream Survey; TEA-Tidewater Ecosystem Assessment; MGS-Maryland Geological Survey; FISH-Fisheries Service. (The following are non-DNR monitoring partners): USGS-United States Geological Survey; ASIS-National Park Service, Assateague Island National Seashore; MCBP-Maryland Coastal Bays Program; UMCES-University of Maryland Center for Environmental Science; VIMS-Virginia Institute of Marine Science; MDE-Maryland Department of the Environment; USACE-United States Army Corps of Engineers; UDCMS-University of Delaware College of Marine Studies.

DNR, the National Park Service and MCBP volunteers all routinely monitor water quality. The United States Geological Survey (USGS) analyzes ground water inputs to the estuary. DNR also monitors stream health, sediment quality and harmful algae blooms. Habitat monitoring is conducted by the Virginia Institute of Marine Science through an annual aerial survey of seagrass bed distribution, while macroalgae abundance and distribution and shoreline change is tracked by DNR. The Maryland Department of the Environment (MDE) teams with DNR to collect data on wetlands. Fish, blue crabs, shellfish and benthic communities are surveyed by DNR and VERSAR while fish kills are monitored by MDE and exotic species abundances were surveyed by the University of Delaware.

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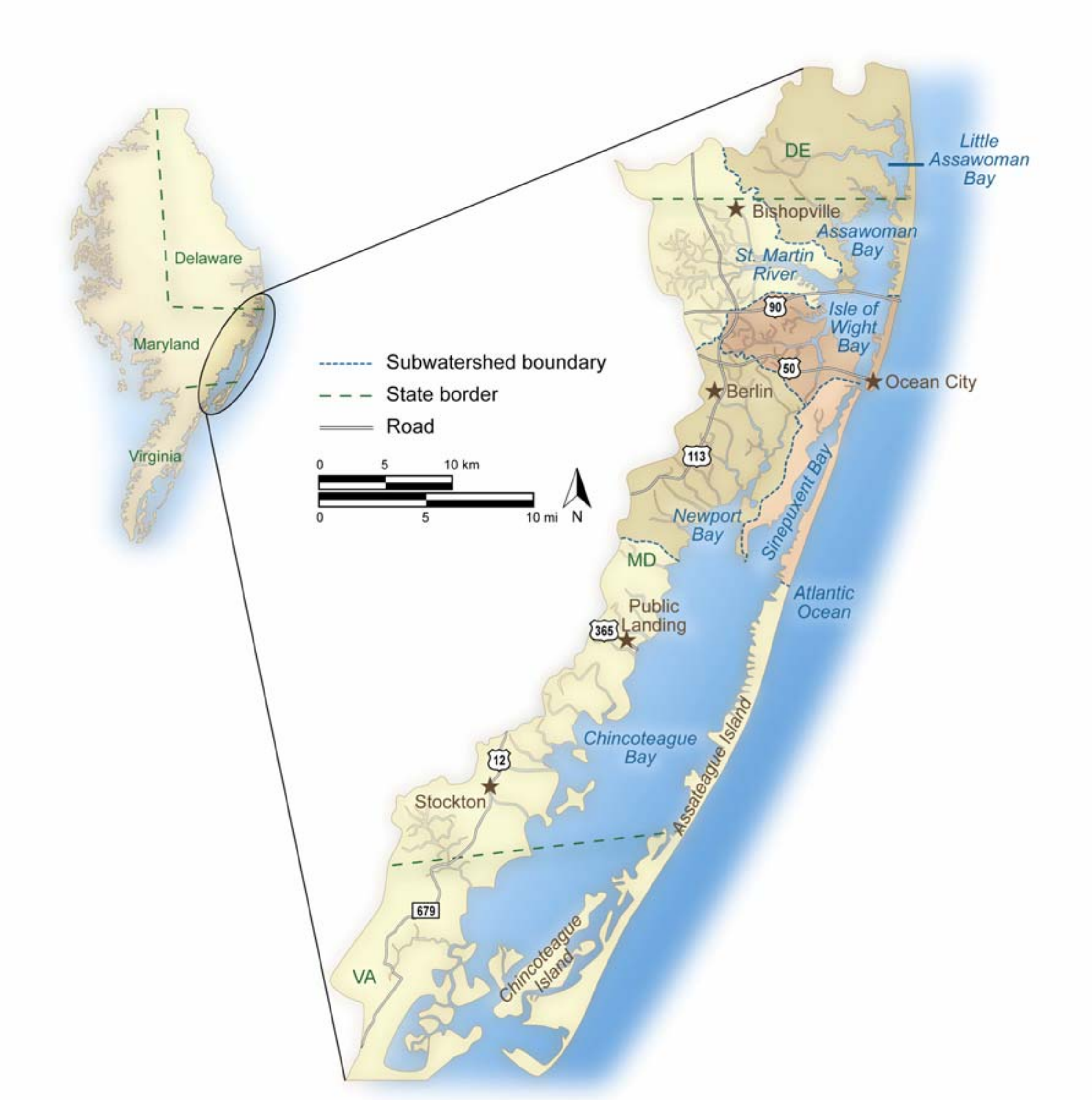

Figure 1.1.1 General location of Maryland's Coastal Bays along the east coast of the United States. The watershed area of each of the Coastal Bays is also shown.

Chapter 1.2

The Maryland Coastal Bays ecosystem

From: Wazniak, C. and M. Hall. The Maryland Coastal Bays ecosystem. In: Maryalnd's Coastal Bays: Ecosystem Health Assessment 2004.

Ecosystem background

The Coastal Bays are estuaries: areas where fresh water mixes with salt water. Due to the flat landscape and sandy soils, rainwater seeps into the ground quickly and groundwater serves as a major pathway of freshwater to the bays. Salinities in the open bays are close to seawater while small portion of the upstream reaches of rivers and creeks remain fresh (Figure 1.2.1). Circulation in the bays is controlled by wind and tides. Tidal exchange with the Atlantic Ocean is limited to two inlets, one dividing Fenwick and Assateague islands and the second in Virginia south of Chincoteague Island. Tidal range near the Ocean City Inlet is more than 3.4 feet, while it drops to 0.4 feet in the middle of Chincoteague and 1.5 feet in Assawoman Bay (UMCES 1993). The Coastal Bays overall are classified as microtidal. Flushing in the bays (the amount of time it takes to replace all of the water by freshwater and ocean exchange) is very slow. That means that contaminants such as nutrients, sediment and chemicals that enter the bays tend to stay in the bays. Because the systems are shallow and have relatively long water residence times, increased nutrients can have a disproportionate effect relative to the nation's larger and deeper bays such as the Chesapeake, Delaware, Raritan, Narragansett, San Francisco and Puget Sound.

<u>Influence of the Ocean: Barrier Islands</u>

Barrier islands are rocky, sandy islands and beaches, dunes, and wetlands located along the Atlantic and Gulf coasts. There are 295 barrier islands along the U.S. coastline (Leatherman 1988). These beaches and the wildlife resources of these islands attract thousands of tourists and millions of dollars to coastal communities every year. Barrier islands serve two main functions in the Coastal Bays ecosystem. First, they protect the coastlines from severe storm damage. Second, they harbor several habitats that are refuges for wildlife.

Natural barrier island processes help create and maintain habitat and benefit circulation. For example, newly formed inlets often amplify tidal flushing. Many inlets have existed along Fenwick and Assateague islands over the past 400 years, including the Ocean City Inlet, which was formed during a major storm in 1933. During storms, ocean water can wash over the barrier islands, carrying sand from the ocean beaches to the bays. This overwash provides a sediment source for the creation of salt marshes and seagrass beds.

Many marine creatures find shelter in extensive marsh lands along the coast. Protected by islands, these salt marsh nurseries add millions of dollars to the economy through commercial and sport fishing opportunities. (Assateague Island National Seashore 2004) Of all the barrier islands between Maine and Mexico; Assateague is one of the last still in a natural state. It's beaches, lagoons and maritime forests offer a rare solitude not far from a rapidly developing coast.

Rising sea-levels and predominant winds from the northeast cause a landward migration of the islands. During storms, overwash of the islands by the sea pushes sand to the mainland side in large quantities. Strong winter winds blowing predominantly from the northeast also pushes sand towards the land. Summer hurricanes and winter storms called "Nor' Easters" account for the most dramatic short-term changes to the islands. A large hurricane can overwash large areas of the islands.

These same wind and weather patterns also move sand generally from north to south. At natural inlets sand tends to erode from the north and accrete (accumulate) on the south side. Where man puts hardened structures like jetties or groins in place, the opposite is true- sand blocked on its normal southerly migration piles up on the north side of a jetty but is eaten away on the south side by the eddy that is created.

For example, a hurricane opened the Ocean City Inlet in 1933 (the inlet separates Fenwick Island from Assateague Island to the south). To keep the channel navigable to the mainland, the U.S. Army Corps of Engineers constructed two rock jetties. Although the jetties stabilized the inlet, they altered the normal north-to-south sand transport by the longshore currents. The result is that sand built up behind the north jetty and the sand below the south jetty was quickly eroded. The accelerated erosion has shifted Assateague Island almost one-half mile (.8 km) inland. In a very short time, human interventions have permanently altered the barrier island profile. (http://science.howstuffworks.com/barrier-island4.htm)

Influence of the Ocean: hydrodynamics

River input to the Coastal Bays is low and groundwater is an important source of freshwater inflow. Circulation in the bays is mainly controlled by winds and tides. Tidal range near the Ocean City Inlet is more than 3.4 feet, while it drops to 0.4 feet in the middle of Chincoteague and 1.5 feet in Assawoman Bay (Boynton et al. 1993). Flushing rates have been estimated for the northern segments as follows: Isle of Wight Bay 9.45 days, Assawoman Bay 21.2 days, and St. Martin River 12 days (Lung 1994). The flushing rate for Chincoteague Bay may be as long as 63 days (Pritchard 1969). The actual residence time of any constituent would vary from the flushing time because of its water column kinetics. Processes such as algal uptake and settling of phytoplankton would tend to decrease the residence time while nutrient recycling would increase the residence time. Intense benthic – pelagic coupling, which is common in systems such as these, increases the impact of contaminants such as nutrient, sediment and chemicals entering the bays.

Nutrient Loading / comparison to other estuaries

Since point sources (e.g. 3 industry and 4 wastewater treatment plants) are heavily regulated in the Coastal Bays, the estimated contribution of nutrients is small (<5% of total nutrients) (UMCES 1993). Nutrient inputs to the Coastal Bays are dominated by non-point sources (e.g. surface runoff, groundwater, atmospheric and shoreline erosion). The amount of nutrients coming from an area is largely dependent on the predominant landuse with agriculture and developed lands generally contributing more nutrient than wetlands and forests. The large variety of non-point sources and pathways makes estimates of relative contribution from different land uses difficult. Current estimates suggest that one-third of nutrients entering the bays come from agriculture sources (Bohlen et al 1997). Efforts are presently underway to refine these estimates using data collected in the Coastal Bays watershed.

Table 1.2.1 Key physical characteristics of each bay segment.

Bay Segment	Drainage area (km^2)	Average depth (m)	Surface area of bay (km^2)	Watershed: Surface area ratio	water volume (m^3*10^6)	Watershed: water volume	Flushing rate (days)
Assawoman	24.7	1.20	20.9	1.18	27.0	0.91	21.2
Isle of Wight	51.8	1.22	21.1	2.45	22.85	2.27	9.45
St. Martin River	95.5	.67	8.40	11.4	5.63	16.96	12
Sinepuxent	26.7	0.67	24.1	1.1	16.5	1.62	U
Newport	113	1.22	15.9	7.1	19.4	5.82	U
Chincoteague (MD)	141	1.22	189	0.75	231	0.61	63
Chincoteague (VA)	174.5	U	188	0.93	143.5	1.22	U
Coastal Bays System	452	1.0	282	1.6	322	1.40	U
Chesapeake Bay	165,759	6.4	18,130	9.1	68,137	2.4	U

Bathymetry/ Surficial Sediment type

Chincoteague Bay, the southernmost of the Coastal Bays, has a drainage area of approximately 141 km^2 and an average depth of 1.22 m. Most of this bay is shallower than one meter, with deeper water in the central channel (7.6 m maximum) pulling the average up. The surface area of the Maryland portion of Chincoteague Bay is 189 km^2. Sediments range from mostly sandy in the eastern part of the bay to silty within the channel to a silt/sand mix along the western shoreline (UMCES 1993, Figure 1.2.2 and Figure 1.2.3). Average grain size as percent of fines is 8.5%, with average percent organic carbon by dry weight at 0.39% (extremely low for an estuarine system). The major source of sedimentation to Chincoteague Bay is storm overwash events and wind erosion from Assateague Island, with stream sedimentation providing relatively little contribution.

Moving north, **Newport Bay** drains approximately 113 km^2 of land area. The average depth of the bay proper is 1.22 m with a maximum of 1.9 m in a central channel. Newport

Bay has a surface area of 15.9 km^2. Sediments are fine-grained, containing mostly silt with little clay (Wells et al. 1996,, Figure 1.2.22 and Figure 1.2.3). Total carbon averaged 1.86% for Newport and Sinepuxent bays combined, with a majority of this contribution from organic sources (Wells et al. 1996). Newport generally has higher carbon contents than Sinepuxent due to more marsh and tributary drainage. Due to the low gradient of Trappe Creek and the other tributaries that constitute the major sediment sources for this bay, sedimentation rates are relatively low.

Sinepuxent Bay, to the immediate east of Newport Bay, has a drainage of 26.7 km^2 and a surface water area of 24.1 km^2 (UMCES 1993). This Bay has the shallowest average depth (0.7 m), despite depths around the Ocean City Inlet reaching 7.8 m. Bottom sediments are fairly course, consisting mostly of sand and, to a lesser degree, silt (Wells et al. 1996, Figure 1.2.22 and Figure 1.2.3). Sedimentation mainly comes from storm overwash and wind erosion on Assateague Island and occurs at a higher rate here than in any other Bay (Wells et al. 1996).

Isle of Wight Bay, directly north of Sinepuxent, has a drainage area of 146 km^2 and a surface water area of 19 km^2 including the St. Martin River. The average depth of this Bay is 1.22 m, with a maximum depth of 9.3 m in the Ocean City inlet (maintained by dredging) (UMCES 1993). Sediment is mostly silt, averaging 44% in cores taken from Isle of Wight, St. Martin River, and Assawoman Bay combined (Wells et al. 1994). A higher percentage of sand is found along the eastern portions of Isle of Wight Bay, due to overwash and erosion from Fenwick Island (Figure 1.2.22 and Figure 1.2.3). Total organic carbon averages 1.83% in Isle of Wight, St. Martin, and Assawoman Bay combined, with carbon content reflecting a combination of both terrigenous and planktonic sources (Wells et al. 1994). St. Martin River and Turville Creek sediments contain the least sand and the most clay and have been classified as tidal stream deposits. Major contributors to Isle of Wight Bay sedimentation are Turville Creek and St. Martin River in the west along with sand from Fenwick Island.

The furthest north embayment, **Assawoman Bay**, drains 24.7 km^2 and has a surface water area of 20.9 km^2 (UMCES 1993). This bay averages 1 m in depth, with a maximum of 2.5 m in a central channel. The canal (also called the 'ditch') connecting Isle of Wight Bay with Assawoman averages 4.7 m in depth. Assawoman Bay sediments contain mostly silt with east-west gradient and total carbon properties identical to Isle of Wight Bay (Figure 1.2.22 and Figure 1.2.3). Major sediment contributors to this bay island on the eastern side.

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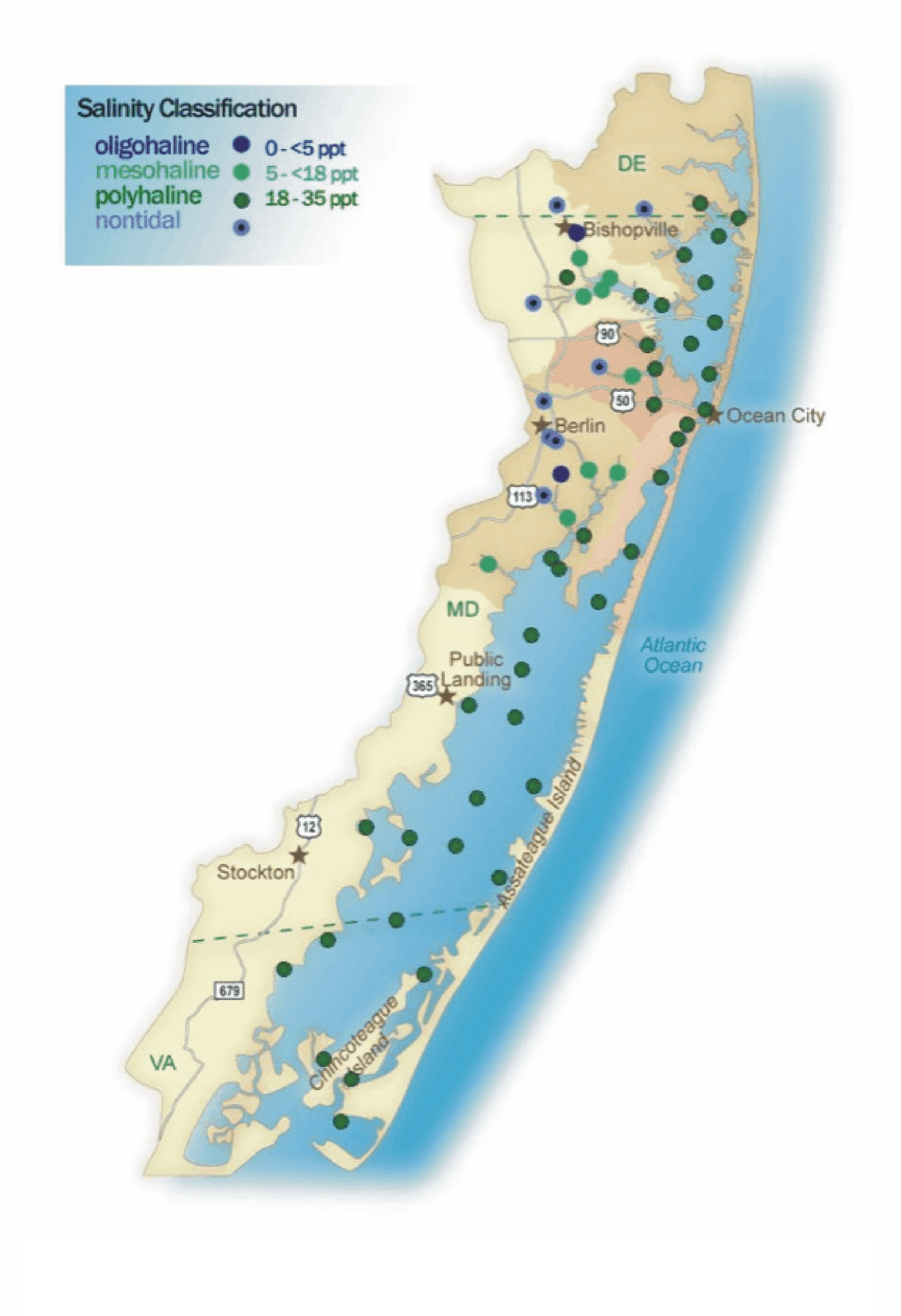

Figure 1.2.1 Salinity classification for water quality sampling stations within the Coastal Bays. Several sampling stations are non-tidal and are thus freshwater.

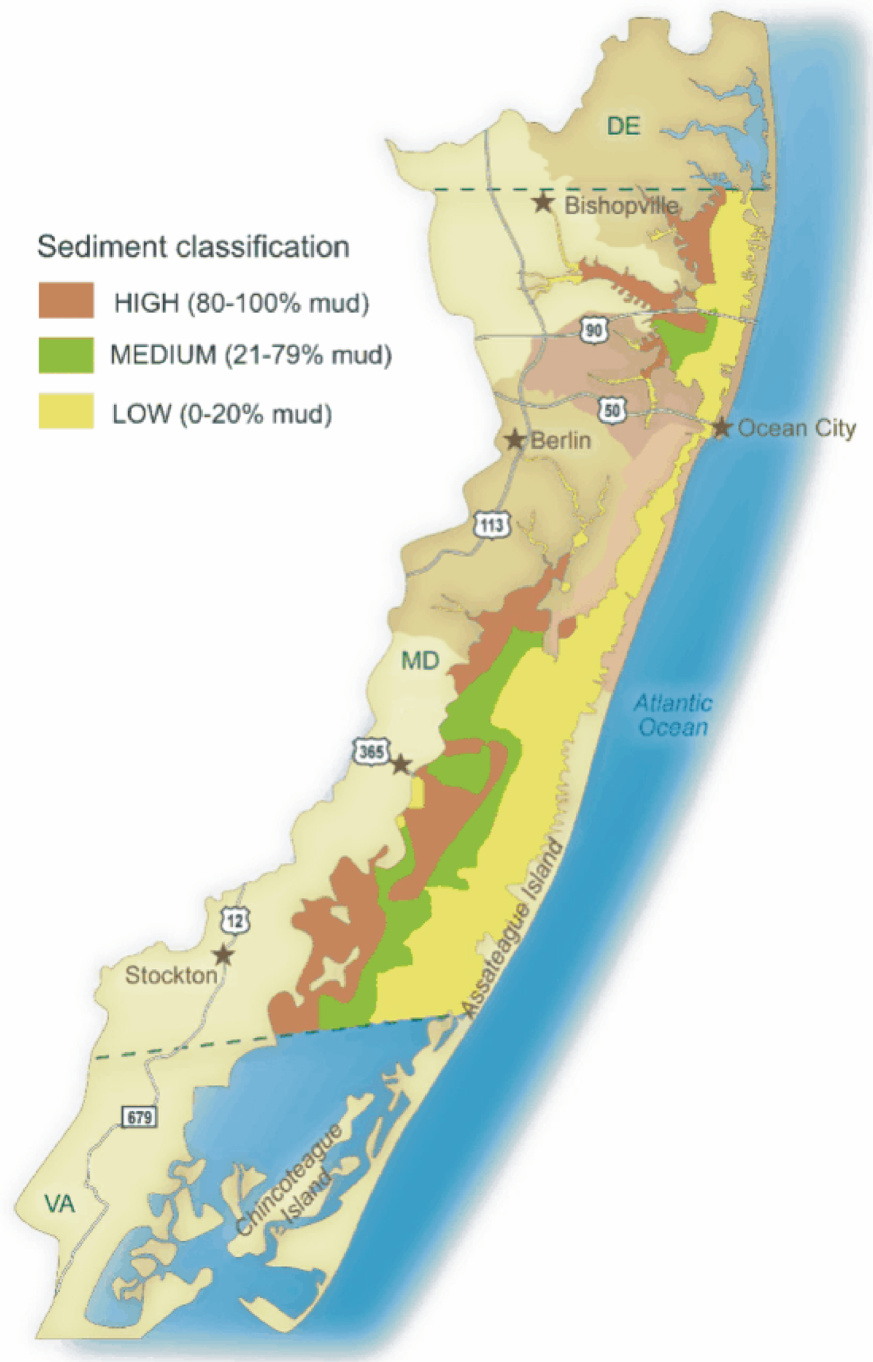

Figure 1.2.2 Percent mud in Coastal Bays shallow bottom sediments.

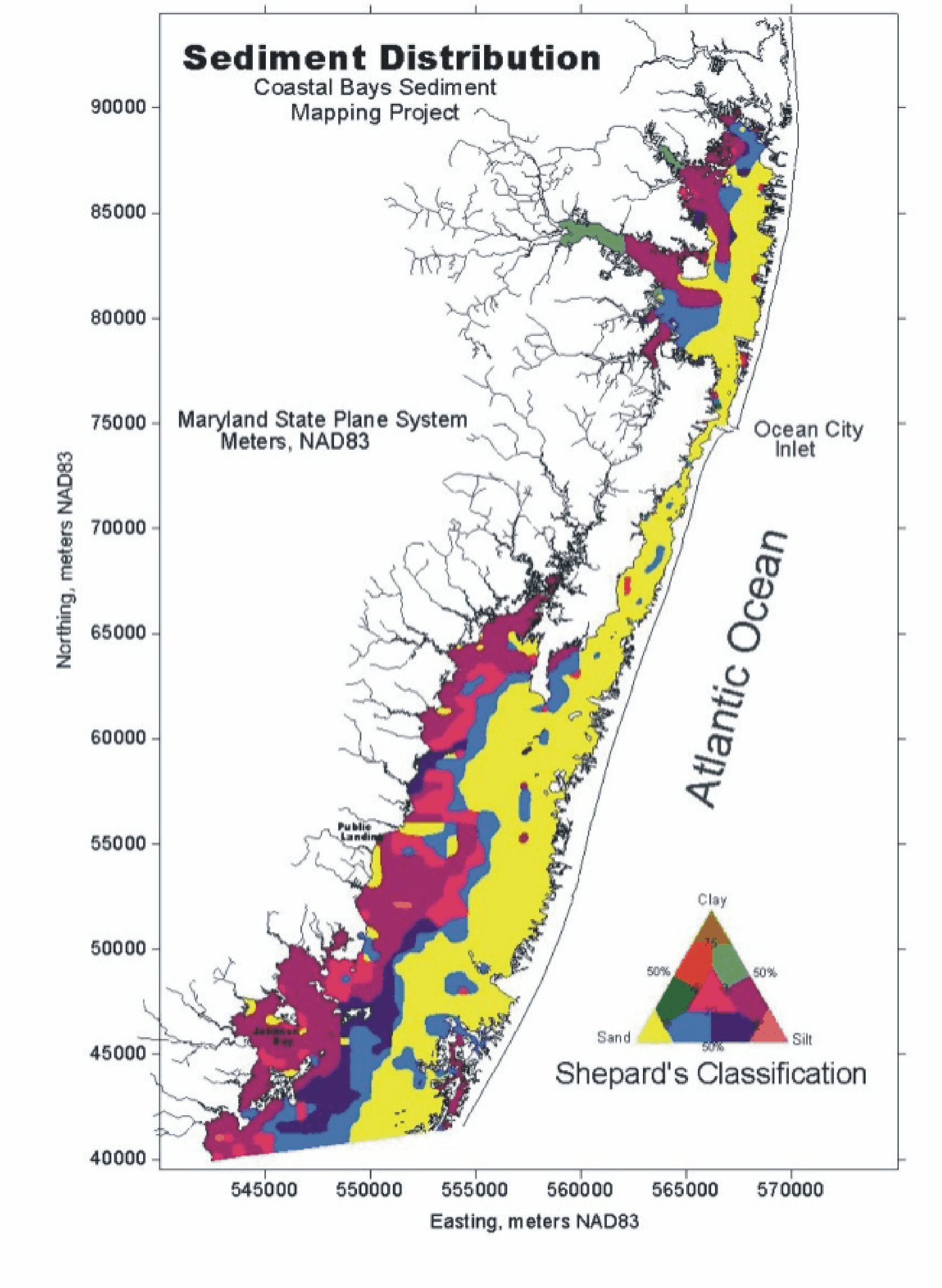

Figure 1.2.3 Sediment distribution in Coastal Bays shallow sediments. The Shepard's classification legend, based on Shepard (1954), shows the relative percentages of sand, silt, and clay in the sediments.

Chapter 2.1
A Brief History of Maryland's Coastal Bays

From: Hall, M. J. Casey and D. Wells. A Brief History of Maryland's Coastal Bays. In: Maryland's Coastal Bays: Ecosystem Health Assessment.

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Abstract
From the early native Americans who hunted and fished the creeks and began to farm the lands, to the Europeans who settled later, to pirates and smugglers looking for hideouts among the perplexing coves and thick marshes, to most recently, the retirees and vacationers in search of more genteel escapes, Maryland's Coastal Bays have beckoned with abundant natural scenery and resources. The human population has gradually risen and, along with natural fluctuations, has promoted change as a common theme within the Coastal Bays ecosystem. Storms come and go, battering the islands and blasting inlets for Atlantic waters, which, if not stabilized, are soon closed by sandy sediments. Stocks of fish and shellfish fluctuate, forcing the waterman and recreational angler alike to be flexible. Other natural factors also constantly change. Eelgrass thrived prior to 1930, only to be reduced by a mysterious wasting disease and then returned years later. Shorelines crumble under the unrelenting force of wind and wave, often returning as shoals far from their origin. Algal populations, microscopic cells drifting unnoticed most of the time, can swell in blooms so massive as to change the clarity and color of the water in every direction. As these communities move through this century, changes in the ecosystem both natural and, more increasingly, human-caused will shape the future of the Coastal Bays.

Pre-History: the Pleistocene Epoch
The Maryland Coastal Bays are located on the Atlantic margin of the Delmarva Peninsula, which lies entirely within the Atlantic Coastal Plain Province. The Delmarva Peninsula was formed over the last 5 to 10 million years. During the late Miocene and early Pliocene Epochs, extensive gravel sheets were deposited over a large area of the coastal plain, forming the general outline for the present day configuration of New Jersey, the Delmarva Peninsula and Maryland's western shore (Owens and Denny, 1979). Through the multiple glaciations of the Pleistocene Epoch, the Delmarva Peninsula continued to take on its present-day shape. During sea level low stands, the ancestral Delaware and Susquehanna Rivers deposited large volumes of sandy sediments on the Atlantic shelf. These sediments were transported and deposited onto the coastal margins of the Peninsula during the ensuing sea level rise or transgression. These transgression deposits are evident today. Based on geomorphic features and subsurface data, Demarest and Leatherman (1985) identified and mapped five distinct linear physiographic

features along the Delmarva Atlantic shore. They attributed each of these features to a distinct sea level high stand ranging in age from over one million years to 60,000 years. The last (and youngest) feature corresponds to the present-day mainland shoreline along Sinepuxent and Chincoteague Bays.

At the height of the last glacial period of the Pleistocene epoch, roughly 18,000 years ago, sea level was 120 meters below present level (Pielou, 1991). As a result, the continental shelf was exposed, with Maryland's Atlantic coastline located approximately 97 kilometers east of present location. Global temperatures began to rise around 17,000 years ago, marking the beginning of the Holocene epoch. The coastal bays started to resemble their present day configuration within the last 5,000 years when sea reached a level approximately 6 to 7 meters (~20 ft) below present mean sea level and started to flood the study area (Figure 2.1.1). Carbon 14 dates from peat and sediment data from cores collected in Chincoteague Bay and Assateague Island provide evidence of the existence of back bay or lagoonal environments, suggesting that barrier islands existed seaward of Delmarva mainland for at least the past 4,500 years (Biggs, 1970; Toscano et al., 1989), sheltering the mainland shore. Their general morphology would be controlled by wave climate, tides, sediment texture and supply as well as the antecedent topography of the exposed shelf. The northern bays (Assawoman and Isle of Wight Bays in Maryland, Rehoboth, Indian River, and Little Assawoman Bays in Delaware) were formed as the stream valleys of major drainage systems flooded (Wells, 1994; Chrzastowski, 1986). These bays are separated from the ocean by barrier islands that form adjacent to eroding headlands, a major source of sediments. Further south, one or more barrier island spits (similar to present day Assateague Island) probably existed separating Chincoteague Bay from the ocean. The barrier island spit, whether a single island or several, probably grew in a southern direction, maintained by a strong littoral transport of sediment.

First contact: 900 – 1524 A.D.
The first Native Americans are thought to have entered the present Maryland Coastal Bays watershed around 10,000 years ago. These first human visitors are believed to have only used the region as an intermittent hunting ground, forming no permanent settlements. True settlement was not likely to have occurred until around 900 A.D. with the beginning of maize agriculture (Rountree and Davidson, 1997). These earliest settlers built small villages of low reed huts along tributaries some distance from the bays. They gathered nuts from oak-hickory and oak-pine forests and tubers from marsh plants, known as tuckahoe. They fished for anadromous fishes (striped bass, white perch, shad) by weir in the tributaries, leaving no evidence of watercraft other than small dugout canoes. They also collected the abundant oysters, clams, and crabs from the shallows.

Native Americans of this period were organized into several localized chiefdoms, including the Pocomokes, Assateagues, and Chincoteagues. They spoke an Algonquin dialect, making them part of this large regional confederacy. They formed small settlements, but probably moved often in search of new farmland or gathering grounds. Before European contact, the population of the Coastal Bays watershed most likely never exceeded 300 permanent residents with many more occasional visitors (Hager, 1996).

Second contact: 1524 – 1850
The first Europeans to visit Maryland's Coastal Bays region are believed to have been the crew of Giovanni da Verrazzano in 1524. Verrazzano, sailing under the sponsorship of King Francis I of France in an attempt to find a short passage to India, explored the east coast of North America from 30° to 50° latitude (roughly modern-day North Carolina to Maine). He sent 20 of his crew ashore near the present-day Virginia-Maryland border and they explored inland to the Pocomoke Swamp, where they were forced to turn around (Truitt, 1971). Verrazzano kept a journal of his travels and his descriptions of the landscape and the natives led to the accepted theory that he was the first European to explore this area.

In 1649, the *Virginia Merchant* sailed for Jamestown, but was struck by a terrible storm. The battered ship anchored off of present-day Assateague and sent a small group ashore to explore the island. The ship was unable to return as scheduled to retrieve the party. As a result, ten of the group died of exposure on the wind-swept island. Without provisions, the remaining party consumed six of the ten dead in order to survive. Only the arrival and subsequent hospitality of a group of Native Americans saved the remaining party members. One of the exploration party, Henry Norwood, recorded the details of this expedition, including a description of how the Native Americans provided them food and shelter until an English settler escorted them first to his nearby plantation house and then back to Jamestown (Truitt, 1971).

The first European settlement of the lower Eastern Shore of Maryland occurred prior to 1649, as evidenced by the local settler who helped rescue the Norwood party. At first, present-day Worcester and Wicomico counties were part of Somerset County, named for the sister of the landowner, Cecil Calvert (then Lord Baltimore). Calvert later divided all of his land (from the Virginia line to just north of Philadelphia) into two counties, the southernmost extending from the northern border of present-day Delaware to the present-day border with Virginia and named Worcester County. However, these counties never materialized and the land was slowly parceled out over the next half-century.

The first European settlers were most likely farmers, hunters and trappers, and fishermen (Hager, 1996), not unlike their Native American predecessors. Frequent storms through the late 1700s and early 1800s opened and re-opened inlets to Sinepuxent bay north of Tingles Island. These inlets provided a brackish environment conducive to oyster establishment and consequent harvest. However, the area was geographically remote and, until railroads were established in the 19th century, population was generally small with few established settlements. This remoteness, as well as ready access to the ocean, led to the popularity of the Coastal Bays as a hideout for pirates in the early 1700's (including Edward Teach, a.k.a. Blackbeard). Later, Civil War draft-dodgers from both sides escaped into the forests and marshes, as did prohibition era rum-runners in the early twentieth century.

Into the Twentieth Century: Big Changes

<u>Demographics</u>
Following the Civil War, advances in transportation led to an increase in population growth. Post-war disillusionment led to a small-scale flight from eastern cities into more remote areas,

including those surrounding the Coastal Bays (C. Petrocci, pers. comm.). Colonel William Whittington was granted most of Assateague Island in 1702, which he subdivided into parcels for livestock grazing (Truitt, 1971). However, few of the parcels sold and most became vacant lands. Anticipation of a railroad terminal connecting Ocean City to Washington and Baltimore led to a marked increase in land speculation in the 1870's. However, the project never materialized, and many of the purchased plots in Ocean City also became vacant. Ocean City was already a popular resort destination during this period, with several hotels opened near the beaches. Ocean City did not become an incorporated municipality until 1880 and, despite relatively rapid growth throughout the early twentieth century, did not build a wastewater treatment plant until 1937.

Development proceeded through the 1900s, from small communities of watermen and farmers to booming resorts and beach access communities currently present in and leading into Ocean City. Advances in transportation certainly fueled these increases, the aforementioned railroads leading the way. In 1951, the Bay Bridge crossing the Chesapeake Bay from Annapolis to Kent Narrows opened. This bridge issued in a new era of population growth, as not only vacationers, but more permanent residents found it easier to get to and from property near the ocean (I. Fehrer, pers. comm.). This trend continued, despite a series of strong tropical storms and hurricanes through the 1950s and '60s. Development centered on Fenwick Island in Ocean City and in West Ocean City on the mainland. Largely in response to this run-away development, the State of Maryland purchased the northern part of Assateague Island and established Assateague State Park there in 1964. In 1965, the remainder of Assateague Island was designated a National Seashore to be managed by the National Park Service.

On the mainland, outside of Ocean City, development and population growth remained slow throughout the twentieth century. Agriculture was and is the mainstay of this area. The aforementioned transportation increases led to a shift from regional markets to Washington and Baltimore. Large-scale production of chickens began in the late 1960s, with the Perdue Company opening its first broiler processing plant in 1968 in nearby Salisbury. Currently, the population outside of Ocean City remains relatively low and the lifestyle "comfortably rural" (Hager, 1996). However, the disproportionate population rise in the resort communities masks this observation. In fact, the population of Worcester county has doubled from 1940 to 1996 (Table 2.1.1), a fact made more interesting in that nearly three centuries were required to attain the 1940 population (Hager, 1996).

<u>Natural Resources</u>

The myriad and often ephemeral fisheries of the Coastal Bays define not only the development of human communities on land, but also serve as perhaps the only record of ecological conditions during the post-Civil War period through the early twentieth century. Frequent hurricanes opened inlets in several portions of the islands, including the aforementioned Sinepuxent inlet and another at Green Run in 1868. The latter led to a lucrative oyster harvest in the Bays until its closure in 1880. Worcester county and Ocean City had money for cost sharing with the United States Army Corps of Engineers (USACE) to build an inlet in 1929. However, the stock market crash later that year caused the project to be postponed. Ironically, a hurricane came through in 1933 and created what is now the Ocean City inlet. In 1934, the USACE stabilized the inlet as it was navigable and most believed that the increased salinity would lead to productive Eastern oyster (*Crassostrea virginica*) harvests. The inlet did have profound effects on the fauna of the Coastal Bays, as the salinity rose to that of ocean water virtually overnight. The effects on the oyster industry were not as expected – the influx of ocean water allowed predators to flourish, as well as competitors that vied for space with spat. Disease may have also contributed to the decline of oyster harvests. Three diseases are present in Coastal Bays; FSO (a higher salinity relation to MSX), Dermo, and some MSX. The combination of increased predation, fouling, disease, and over-harvesting probably led to the decline of oyster populations to the relicts of today (M. Tarnowski, pers. comm.).

The opening of the Ocean City inlet, while proving detrimental to oysters, was a boon for hard clams (*Mercenaria mercenaria*). Before the inlet, hard clams were confined to the southern portions of Chincoteague Bay where the salinity was high enough to sustain this brackish water species. Clam harvests climbed sporadically through the 1960s, when hydraulic clam dredging came to fore. Currently, clam populations are stable and harvesting effort is relatively low and restricted to non-mechanical recreational harvest.

Bay scallops (*Argopecten irradians*) also sustained a small commercial fishery in the higher salinity areas of southern Chincoteague Bay through the 1920s. New fisheries for this species were anticipated with the opening of the Ocean City inlet. However, the story of the bay scallop is a story of declining habitat, specifically the sea grass beds where they live. Eelgrass declined precipitously through the 1930s due to "wasting disease" and new scallop fisheries never materialized. Bay scallops (*Argopecten irradians*), which had occurred in most of the Coastal Bays during the early 2000s, have not been observed in Chincoteague since 2005. Some scallops still inhabit the northern bays, albeit in very low numbers.

Another popular fishery in the Coastal Bays is that for blue crabs (*Callinectes sapidus).* At times, over 100 boats come out of Chesapeake Bay for spring crab season, taking advantage of the earlier warming. Female Chesapeake crabs tend to be larger, so those watermen crabbing the early Coastal Bays crab season find it more lucrative to return to the Chesapeake. However, some usually stay on to take soft crabs, which molt synchronously in the Coastal Bays (Boynton, 1970). Catch records are available back to 1890 (summarized by Murphy, 1960). The catch was generally low in the 1800s through the early twentieth century, but then increased dramatically, with an overall haul of 3,757,300 pounds in 1950 (Murphy, 1960). Crab populations tend to fluctuate (Davis et. al., 2002) over years, as they did through the 1970s. Harvest continues to vary without trend (1980s through 2013),and average annual catches are around 1,560,000 pounds crabs (hard, soft, and peeler) per year. Like bay scallops, sea grass beds are critical habitat for blue crabs. However, there was no apparent decline in crab harvests during the period between the 1930s and early 1980s when sea grasses were absent and then recovering at low densities (UMCES, 1993). Also, in the early 1990s, the parasite *Hematodinium* was observed killing many crabs in the Coastal Bays.

Finfish have arguably the most tumultuous history among the many Coastal Bays fisheries. Watermen landed millions of pounds of bluefish (*Pomatomus saltatrix*), "fatbacks" (mullet: *Mugil cephalus*), striped bass (*Morone saxatilis*), and weakfish (*Cynoscion regalis*) from the late 1800s through the 1930s (Murphy, 1960). Large numbers of "bunkers" (menhaden: *Brevoortia tyrannus*) were also harvested, mainly for use as fertilizer (Truitt, 1971). However, with the opening of the inlet in 1933, landings from the Coastal Bays declined mainly due to effort shifting to more lucrative offshore fisheries (UMCES, 1993). Despite a paucity of landing data, many species remained abundant in the Bays through the 1940s (M. Simpson, pers. comm.). Harvest remained low through the mid-twentieth century until 1970, when commercial landings increased dramatically. A record harvest of 103,635 pounds was landed that year, mostly bluefish, weakfish, and spot (*Leiostomus xanthurus*). This landmark year signaled subsequent increases in landings from the bays (UMCES, 1993). Still, the yields from oceanic fisheries dwarfed those from the Coastal Bays, and more emphasis has been placed on recreational fishing in recent years.

Despite the popularity of the Coastal Bays as a recreational fishing site, little historic data is available. However, anecdotal evidence thrives in the collective memories of many long-time residents. Many fisheries seem to cycle, reflecting the history of transitions in the Bays. For instance, spot were abundant in both commercial and recreational catches in the 1930s and 1940s, then were not seen for a decade or more, before returning in the 1960s (M. Simpson, pers. comm.). Shellfish fishing, excluding blue crabs, seems to follow the trends mentioned earlier for commercial fisheries. However, blue crabs have been harder to find for recreational "chicken-neckers" in recent years despite no apparent crash in commercial harvest (D. Wilson and M. Sampson, pers. comm.). This trend is reflected in decreased sales in recreational crab pots and associated gear (C. Cummins, pers. comm.). This trend may indicate a changeover in how visitors choose to recreate in the bays, as success usually requires some knowledge of where and when to crab.

Recreational fishing for summer flounder (*Paralichthys dentatus*) is of special mention. Many vacationers have historically come to the Coastal Bays to fish for flounder. This tradition continues to this day. From the late 1960s through the 1970s, flounder were the most sought after recreational fish (M. Sampson, pers. comm.). However, both anecdotal and Maryland Department of Natural Resourcestrawl data indicate that flounder have declined in recent years (see Fisheries chapter of this assessment- Chapter 7.1); B. Abele and M. Sampson, pers. comm.). With catches down, many anglers are shifting to the more productive offshore fishing grounds.

As telling as observations of sport fish abundance and catchability are, some anomalous observations may provide further evidence of the fluctuations present in the Coastal Bays. In the late 1980s, Northern puffer fish (*Sphoeroides maculatus*) were so abundant as to spawn a small-scale fishery. This boost seemed to correspond with an increase in serpulid worm populations, at times so numerous that masses of their calcareous casings were navigation hazards. In the late 1970s and into the 1980s, a spring run of monkfish (*Lophius americanus*) occurred on an annual basis (M. Sampson, pers. comm.). Maryland Department of Natural Resources Fisheries have observed them coming in the Ocean City inlet each spring to spawn in varying numbers annually since 1971, though never in large numbers. Storms, which had occurred frequently through the early 1970s, drastically declined during this time. These two examples are pure speculation, and these occurrences could be coincidental. Booms in species abundance, however ephemeral, are rarely random events. However, they serve to illustrate the nearly infinite interactions present in this ecosystem.

In summary, the natural opening and closing of inlets in the barrier island was a major force in the success or failure of early commercial and recreational fishing efforts in the Coastal Bays (Figure 2.1.2). An article featured in <u>Maryland Fisheries</u> journal published by the Maryland Conservation Department in March 1931 emphasizes this assertion. The article comments on the severe storm of February1920 that opened a wide, navigable inlet in what is now upper Assateague Island, stating: "The results from the opening of this inlet were almost magical. Crabs came up from the lower Chincoteague Bay and the sponge crab was found above Ocean City. The clamming industry began almost at once as a result of the salting of the water, and in five years clams were being taken by the millions. Fishermen were able to make as high as $35 a day clamming. Oysters were planted even above Ocean City and business commenced to thrive. Then the inlet began gradually to close and this was accompanied by the death of shell-fish of all kinds."

The Twenty-first Century: What does the future hold?

Clearly, Maryland's Coastal Bays have been the scene of tremendous change over time. But what changes may come as this century progresses? Human population is expected to climb steadily (Hager, 1996), with many more permanent residents as opposed to summer visitors (C. Cummins, pers. comm.). The changes in landscape, especially as farmland is converted to residential development in the greater watershed, will bring about added stresses to the Bays ecosystem (Hager, 1996). Proactive management of development, along with improvements in wastewater and run-off projects, will be necessary to preserve the integrity of this ecosystem. This necessity runs concurrent with the population trend, for it is precisely the opportunities afforded by this ecosystem integrity that draws people to this area. A survey of boaters strongly supports this assertion; a majority chose "good fishing", "scenic quality", or "peaceful location" as their main reasons for living near or visiting the Coastal Bays (Falk and Gerner, 2002). The Coastal Bays community, both ecological and human demographic, will certainly continue to change over time. The capacity to respond to this change over time should be preserved.

Coastal Bays Ecological and Demographic Timeline

(Note: Location of inlets mentioned in the timeline are shown in Figure 2.1.2)

<u>1820-1844</u>- Oyster harvest coincident with open inlet.
<u>1837-</u>First record of wild ponies.
1844- Inlet opened, closed 1844.
<u>1868</u>-Green Run inlet opened.
    Lucrative oyster industry.
    City of Berlin incorporated.
<u>1874</u> – Hurricane.
<u>1876</u>-The <u>List of Fishes of Maryland</u> published, including Coastal Bays species.
<u>1877</u>- Hurricane.
1878 – Ocean City Life-Saving Station commissioned
<u>1879</u>- Hurricane.
<u>1880</u>-Green Run inlet closed. Oysters declined in Sinepuxent. Ocean City incorporated.
<u>1881</u>- Hurricane.

1882- 2 hurricanes.
1886- 2 hurricanes.
1894- Hurricane off shore.
1908- Submerged aquatic vegetation beds present in upper St. Martin's river.
1914-A Notes on the Fishes at Ocean City, Maryland was published in the journal *Copeia*.
1916-1787 barrels of "choice" fish harvested.
1920-Sturgeon (caviar) fishery declines.
1921-inlet opened. Improved fish and crab populations.
1928-State begins commercial landings survey of shellfish from bays.
1929-1921 inlet closed.
1930- Eelgrass "wasting disease" begins destroying grass beds.
1933 -Hurricane off shore in August. **Storm surge opens Ocean City inlet.**
1934- US Army Corps of Engineers stabilizes Ocean City inlet.
Bird nesting islands created with dredge material.
1935- West Ocean City harbor created by the US Army Corps of Engineers.
1936- Hurricane off shore.
1937- Ocean City sewage plant opens, discharging into Ocean City inlet.
1942 - Harry W. Kelley Memorial Bridge (Rt 50 Bridge) constructed.
1943- Hurricane.
1944- Hurricane and 2 tropical storms.
Fishing (croaker, spot) generally good (through the 1940s).
1948-First dredging of Sinepuxent and Isle of Wight bays.
1950-Perdue opens Showell plant.
1952- State hard clam study.
Chesapeake Bay Bridge opens
1953- Hurricane Barbara.
1955- Tropical Storm Connie.
1958- MSX (Multinucleated Sphere Unknown) oyster disease first reported.
Hey day of leased oyster beds.
1959 - Bishopville Dam built: *The dam was built as a "tumbling dam" to keep the river below open for fishing and small boat navigation.*
1960- SSO and Dermo (*Dermocystidium marinum*, aka *Labyrinthomyxa marina, Perkinsus marinus*) oyster diseases first mentioned.
Tropical Storm Brenda followed by offshore Tropical Storm Donna.
1964-Assateague State Park established.
1965-Assateague Island National Seashore established.
First Worcester County Comprehensive Land Use Plan created.
1967- Tropical Storm Doria.
1968-Ocean Pines Development established.
1969-Seagrass beds and scallops noticed during trawl surveys.
Assateague Ecological Study begins (through 1971).
State ends annual shellfish landings survey.
Ocean City sewage plant upgraded and outflow moved offshore.
1971- Tropical Storm Doria.

Large number of monkfish (*Lophius americanu*s) in spring (through the late '60's into '70's)
1972- Maryland Department of Natural Resources Fisheries Service begins routine trawl and seine surveys.
Federal Clean Water Act passed.
1973- Second span of the Chesapeake Bay Bridge opens.
1975- Seagrass and scallop declines.
1976- Areas of septic tank failure and subsequent water quality violations were identified in numerous towns in the Coastal Bays.
1980s- State Highway Administration stabilize Ocean City bridge
1980-U.S. Army Corps of Engineers identifies need to replenish sand along OC beaches.
1981-The Committee to Preserve Assateague Island held the first of many citizen led conferences focused on aquatic resources.
1982- Begin to see SAV recovery.
1983- First brown pelicans (*Pelecanus occidentalis)*.
Last commercial oyster harvest.
Maryland Department of the Environment intensive surveys commence.
1985- Offshore hurricane Gloria. Hurricane Danny. Tropical Storm Henri.
Maryland bans phosphates in detergents
1986-Virginia Institute of Marine Sciences seagrass aerial surveys begin.
Observed decline in recreational flounder fishing.
1987-National Park Service begins routine water quality monitoring in Newport, Sinepuxent, and Chincoteague bays.
1988-Coordinated beach replenishment (Army, State, local) commences.
1989-Large numbers of pufferfish (*Sphoeroides maculatus*) present.
1990- Focus on Maryland's Forgotten Bays, The Citizens Agenda conference convened.
U.S. Environmental Protection Agency Environmental Mapping and Assessment Program (EMAP) begins (through 1992).
1991-Green crabs (*Carcinus maenus*) established.
1992-Washover event (nor'easter) impacts piping plover habitat.
1993-Brown Tide probable from archival samples.
MD Dept. of Natural Resources begins long-term hard clam survey (includes scallop numbers).
U.S. Environmental Protection Agency joint assessment begins (through 1996).
Maryland Department of Natural Resources Molluscan Inventory begins.
1995- Maryland Coastal Bays nominated to National Estuary Program.
1996- Japanese shore crabs (*Hemigrapsus sanguineus*) established.
All five Coastal Bays were included on Maryland's impaired water list.
Maryland Coastal Bays Program and Maryland Department of Natural Resources hold the first ever Maryland Coast Day on Assateague.
1997- Maryland Department of Natural Resources plants bay scallops.
Maryland Deptartment of Natural Resources Molluscan Inventory study completed.
U.S.Environmental Protection Agency Mid-Atlantic Integrated Assessment begins (through 1998).
Maryland Coastal Bay Program initiated.
Coastal Bays Rural Legacy Program established for land conservation.

1998- Brown Tide (*Aureococcus anophagefferens*) first detected.
Maryland Department of Natural Resources monitors for *Pfiesteria* at 29 stations.
Maryland Department of Natural Resources plants bay scallops.
Army Corps of Engineers completes the Ocean City water resources environmental impact study, the most extensive review of resources and conditions of the Coastal Bays to that date.
1999- Brown Tide blooms
Macroalgae present in large masses.
Maryland Coastal Bays Comprehensive Conservation & Management Plan published
2000- Brown Tide blooms Macroalgae.
National Coastal Assessment (continuation of EMAP) begins (through 2004).
Worcester 2000 Community Visioning workshops held.
2001- Brown Tide. Macroalgae.
Maryland Department of Natural Resources begins routine water quality monitoring at 45 stations.
Blue crab fishery management plan goes into effect.
2002- Brown Tide. Macroalgae.
Scallops found north of Ocean City inlet.
Hard clam fishery management plan goes into effect.
Exotic species survey completed.
Maryland Department of Natural Resources deploys continuous water quality monitors (Bishopville and Turville Creek).
Total Maximum Daily Loads approved for Big Mill Pond, Turville, Herring & Manklin Creeks, and the St. Martin River.
The state Critical Area Program expands to include protections to the Coastal Bays.
Horseshoe crab survey begins.
Maryland legislature passes law to include the coastal bays in the state's Critical Area.
2003 - Brown Tide.
Large masses of boring sponges present.
Total maximum daily loads approved for Newport Creek, Newport Bay and Kitts Branch.
2004- Priority areas for wetland restoration, preservation & mitigation determined.
Stream corridor assessments completed for each bay.
2005 - Continuous water quality monitor deployed at Public Landing.
Coastal Bays Aquatic Sensitive Areas Management and Education Plan completed.
2006- Worcester County produces an award winning Comprehensive Plan.
Sea level rise inundation modeling takes place.
Virginia Institute of Marine Sciences creates a shoreline inventory of natural and hardened shoreline structures.
Maryland Coastal Bays Program begins annual stream chemistry surveys.
Dinophysis bloom detected at Ocean City Inlet.
2007- The old Ocean City dump is cleaned-up and converted into a public kayak launch.
- *Dinophysis* blooms in Bishopville Prong.
- June 7- Newport Creek had microcystin levels of 13ppb and Trappe Creek had 29ppb (*Cyanobium* dominant).

2008 - First Coastal Bays Report Card is published

______- Maryland Coastal Bays Program begins colonial waterbird count
- The Maryland Coastal Bays Program Policy Committee creates the 64,000-acre Newport/Chincoteague
- Land Conservation Area with a goal of protecting 20% of the area (471 acres/yr) by 2015

2009 – Worcester County updates zoning code, removing most large-lot zoning, strengthening the A-1 zone, and keeping growth around existing infrastructure.
- Maryland Coastal Bays Program begins Coastal Stewards Program with Maryland Department of Natural Resources and Assateague Island National Seashore.
–"Shifting Sands" published to highlight the cultural and environmental history and challenges in the coastal bays.
-Significant *Microcystis* bloom in Trappe Creek.

2010 – U.S. Fodd and Drug Administration confirmed presence of diarrhetic shellfish poisoning (DSP) toxins in Maryland waters for the first time (Manklin Creek bloom).
Bloom of *Pseudo-nitzchia* detected in Isle of Wight Bay

2011 - Lizard Hill sand mine reclaimed through the creation of an Atlantic White Cedar community (Bishopville area)
- Terrapin sightings are collected.
- Showell property undergoes floodplain restoration.
–Begin replenishing Skimmer Island.

2012 – Diarrhetic Shellfish Poisoning toxins found in shellfish above the U.S. Food and Drug Administration guidance levels in area that is closed to shellfishing (Bishopville Prong)

2013- The Town of Berlin spray irrigates all wastewater effluent and establishes the first stormwater utility in the county.
- Maryland Coastal Bays Program joins the Environmental Protection Agencies Climate Ready Estuaries Program.
- U.S. Environmental Protection Agency approves new total maximum daily load for the Maryland Coastal Bays.
- Bloom of *Dinophysis* in Manklin Creek.

2014 - Maryland Coastal Bays Comprehensive Conservation Management Plan updated,
-Dredging of Ocean City Inlet and new island created for colonial bird nesting.

Acknowledgements
Many people contributed information to this report, both in the form of hard data and personal anecdotes. Without their insights, a comprehensive understanding of the history of the Coastal Bays would not be possible. Many have been acknowledged in the text, but a full list is included here: Mitch Tarnowski, Carolyn Cummins, Dave Wilson, Charlie Petrocci, Mac Simpson, Mark Sampson, Bob Abele, Ilia Fehrer, Roman Jesien, Todd Burbage, Margaret McGinty, Carol Cain, and Cathy Wazniak. Cel Pietro was invaluable in locating and compiling source materials.

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Table 2.1.1 Historical and Projected Population in the Coastal Bays Watershed

Pre-European (1600s) – around 300 Native Americans.
1600s through early 1900s – sparsely populated; mostly farmers and watermen.
1940 – 21,245
1990 – 35,028
1995 – 40,300
2000 – 47,228 (during summer months, can exceed 300,000)
2010 – 51,451
2014 – 51,675
projected 2020 – 72,117

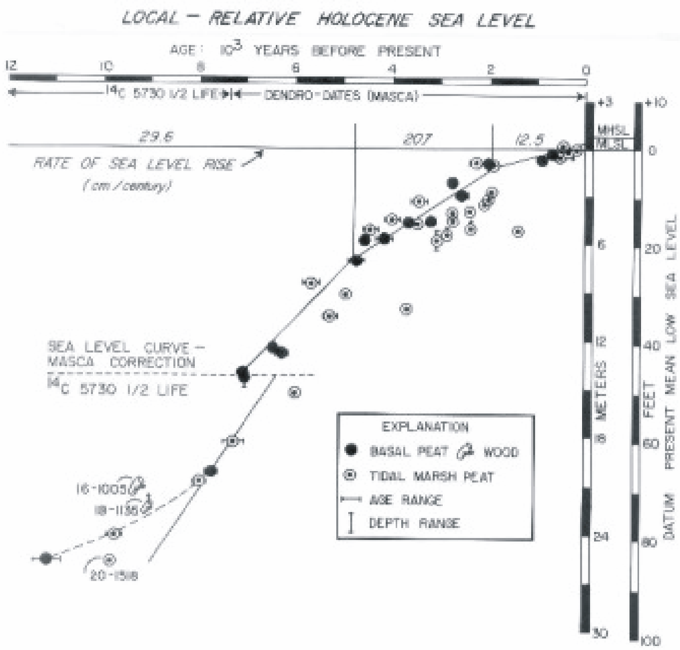

Figure 2.1.1 Local relative sea-level rise curve for the Delaware-Maryland coastal zone based on carbon-14 dating of basal and tidal marsh peat, and wood fragments (Kraft et al, 1987; Toscano et al, 1989). MASCA corrections after Ralph et al (1973). Figure taken from Toscano et al (1989).

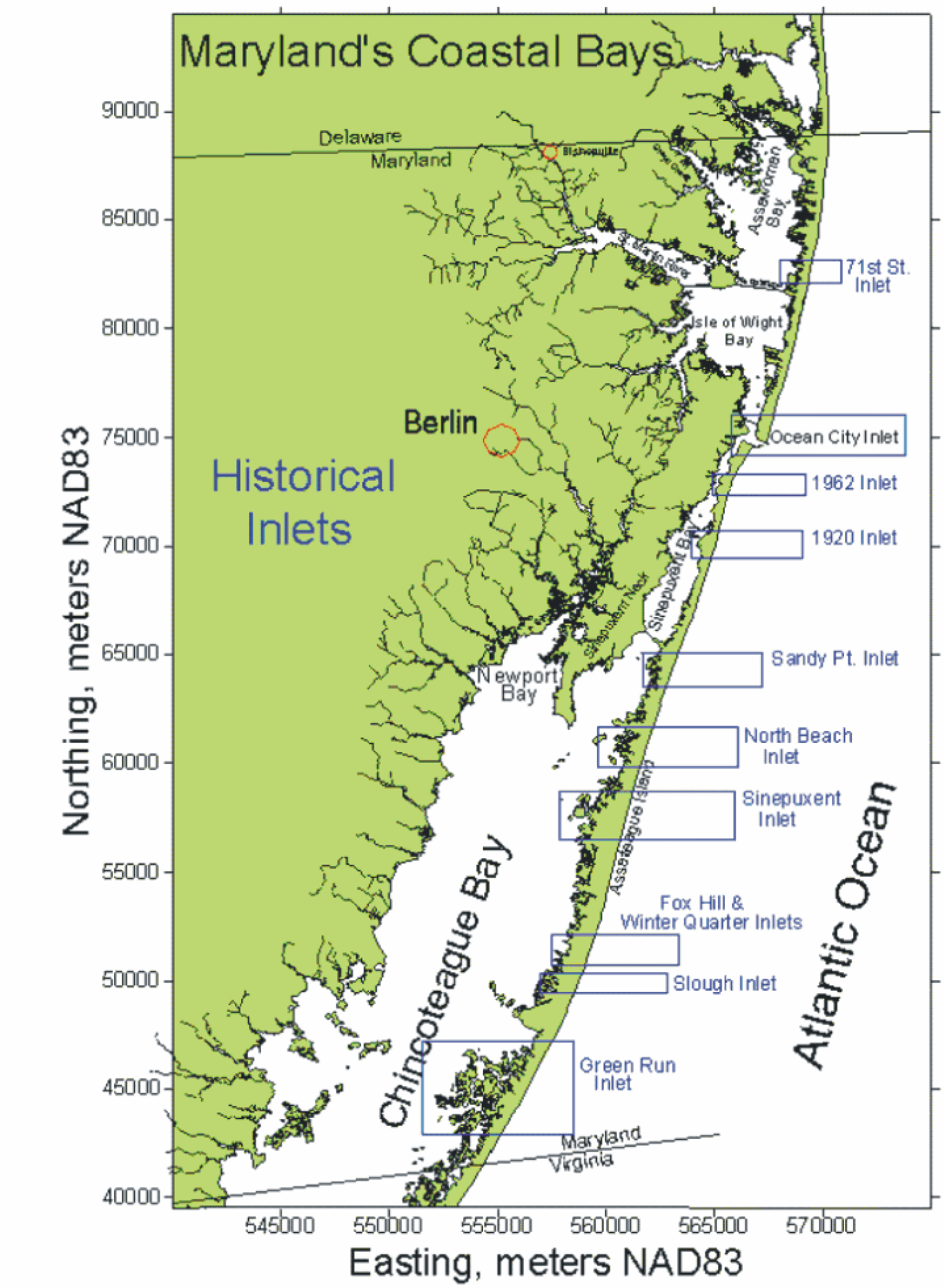

Figure 2.1.2 Historical inlets of Maryland's Coastal Bays. These inlets are described in further detail in the timeline section of the report text.

Chapter 3.1

Nitrate + Nitrite concentrations in non-tidal streams flowing into the Maryland Coastal Bays (2006-2013)

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Abstract
Several monitoring programs have monitored stream enrichment over the past two decades. Natural background concentrations of nitrate in streams nationwide is 0.6 mg/L with concentrations greater than 1.0 mg/L indicating anthropogenic inputs. Newport and Isle of Wight had the highest mean concentrations of nitrate/nitrite while Sinepuxent and upper Chincoteague Bay streams had the lowest. Continued monitoring will be needed to determine if concentrations/inputs begin to change.

Introduction
Nearly every stream in the Coastal Bays watershed has been altered at some point over the past century, having been straightened and/or deepened to promote faster drainage of adjacent land. The natural conditions of local streams are generally flat, sandy and slow moving. Many are tidally influenced as they discharge into the estuary; some originate in upland low-lying areas and are dark stained from tannic acids at the headwaters. The shorter stream reaches in this narrow watershed often have small catchment basins and reduced refugia for biota.

Nitrate + nitrite (NOx) are essential plant nutrients that are readily assimilated by aquatic plants. At excessive levels, however, eutrophication of the stream can occur. Anthropogenic sources of NOx to streams and groundwater include septic systems, wastewater/agricultural/stormwater ponds, leaky sewer lines, and manure fertilizer application.

Data Sets
The Maryland Coastal Bays Program initiated a spring stream water chemistry sampling program in 2006. The purpose of this survey is to document springtime existing conditions over time, pinpoint nutrient hotspots and act as a proxy measure of management efforts within the watershed. Sampling takes place annually in April when flows are typically low and generally reflects higher groundwater discharge to ditches and streams before plant uptake of nutrients takes place. The April timeframe was also chosen to compare with historical Maryland Department of Natural Resources synoptic surveys results and to coincide with Maryland Biological Stream Survey (MBSS) macroinvertebrate sampling through the state Stream Waders program. Samples are collected after a minimum of 48 hours without rainfall. Site conditions are noted, dissolved oxygen, temperature, pH, conductivity and salinity are measured in the field. Water samples are collected and analyzed for total and inorganic nitrogen, phosphorus, and chlorophyll a concentrations. The University of Maryland, Horn Point Laboratory conducts the chemical analyses using standardized and approved protocols.

Management Objective: Improve stream health.. To achieve bay water concentrations of nutrients that meet seagrass thresholds.

Indicator: NOx <1.5 mg/L >1.0 mg/L indicates probable anthropogenic sources

Data Analyses

Summary statistics were done on bay-wide and subwatershed nitrate/nitrite data collected in streams. A time series linear regression was performed to fit a trend line to the data and to determine the strength of the relationship between nitrate and time.

Results

During the period of 2006 – 2013, 41 to 58 separate streams sites were monitored each year, with a sum total of 413 samples collected. The range of nitrate/nitrite (NOx) was 0.00 – 8.82 mg/L (Figure 3.1.1). The bay wide median value is 0.83 mg/L and the mean concentration is 1.51 mg/L. Median concentrations of streams aggregated by subwatershed are presented below in Table 3.1.1 and Figure 3.1.2 displays the box and whisker plot for each sub-embayment.

Newport Bay streams had the highest average NOx concentrations followed by Isle of Wight Bay, Assawoman, St Martin River and Lower Chincoteague. Sinepuxent and upper Chincoteague had the lowest average stream NOx levels. Except for streams in Sinepuxent, which exhibited low concentrations, all other areas typically exhibited wide variation. For all samples, 47.9% were greater or equal to 1.0 mg/L which indicates potential anthropogenic inputs. A closer analysis by individual stream sites over a longer timeframe may reveal minor changes in concentration, but those changes may be imperceptible given the long residence time of groundwater NOx loads. Figure 3.1.3 indicates that as an aggregate, there is no correlation with time.

For comparative purposes the five fresh water streams below in Table 3.1.2 show decreasing concentrations between the DNR Synoptic Surveys (1999-2003) and the mean spring survey conducted by Maryland Coastal Bays Program (2006-2013). However, these concentrations do not appear when comparing the spring survey with year-round means, though seasonality may explain the difference.

Figure 3.1.1 Mean stream Nitrate/Nitrite, NOx, concentrations (2006-2013).

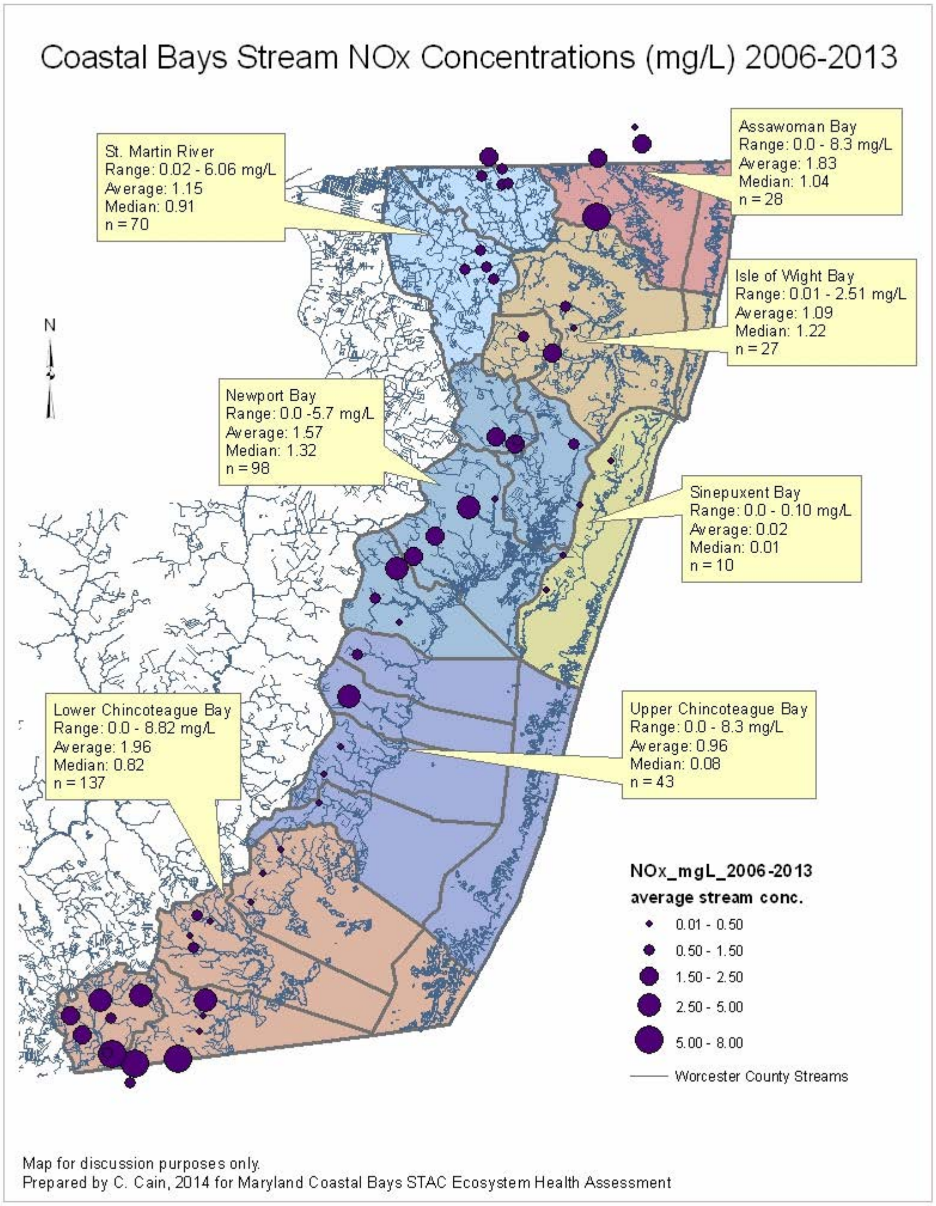

Table 3.1.1 Median concentrations in stream nitrate/nitrite, NOx, by embayment.

Embayment	Median NOx (mg/L)	# samples	# sampling sites
Assawoman Bay	1.04	28	5
St. Martin River	0.91	70	9
Isle of Wight Bay	1.22	27	4
Sinepuxent Bay	0.01	10	3
Newport Bay	1.32	98	12
Upper Chincoteague Bay	0.08	43	5
Lower Chincoteague Bay	0.82	137	20

Figure 3.1.2 Box and whisker plots of Nitrate/Nitrite, NOx, concentration by subwatershed.

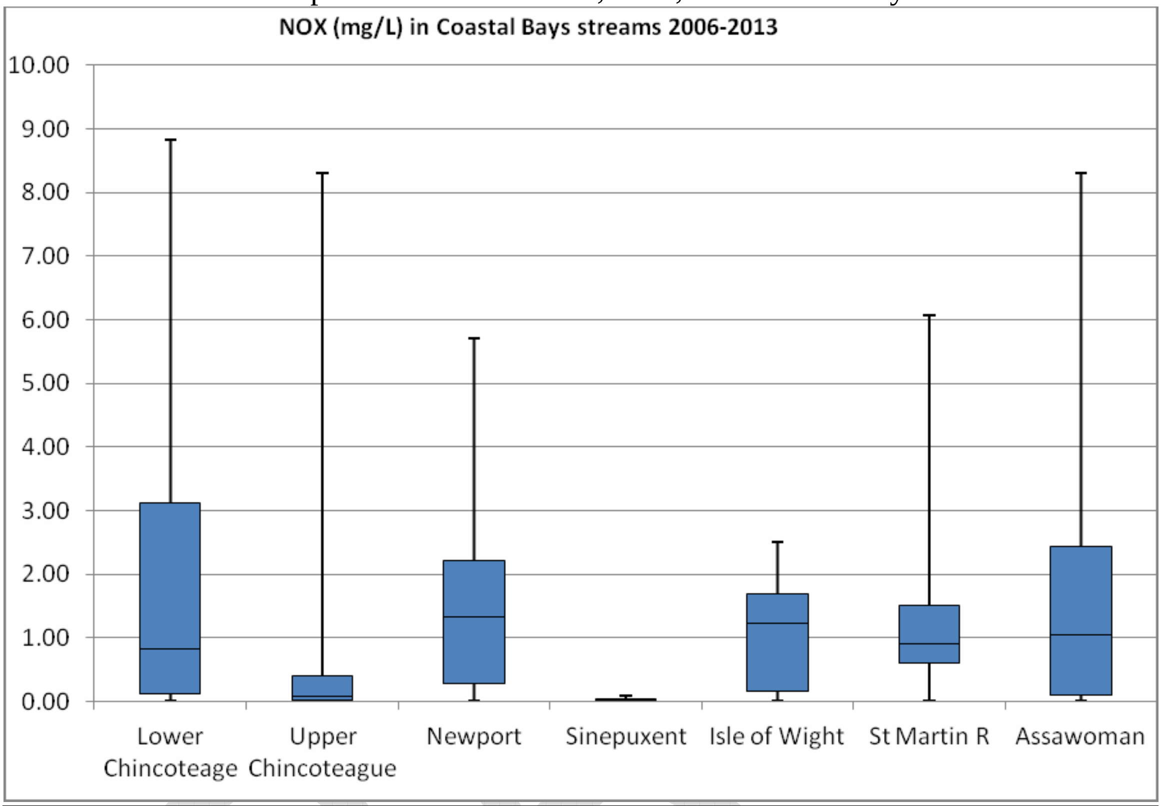

Figure 3.1.3 Timeseries of NOx concentrations in Coastal Bays streams over time.

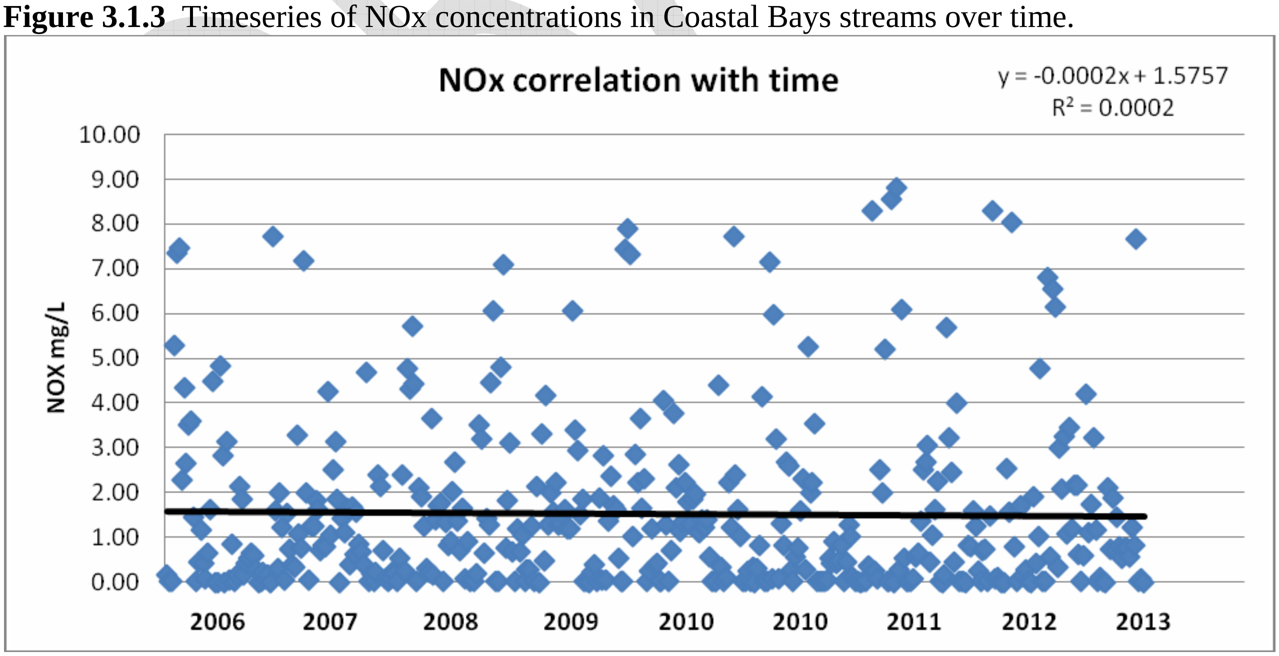

Table 3.1.2 Median concentrations of nitrate + nitrite (mg/L) over time via multiple monitoring surveys

		Monthly sampling, year round (years sampled)		Spring only surveys (years sampled)		
Drains to	Stream name	MCBP [1]	DNR[2]	MCBP streams[3]	USGS[4]	DNR Synoptic[5]
Newport Bay	**Hudson Branch**	2.35 (2010-2013)		1.62 (2006-2013)		1.9 (2003)
Newport Bay	**Bottle Creek**	2.21 (2006-2013)	2.23 (2007-2013)	2.16 (2006-2013)		4.05 (2003)
Newport Bay	**Trappe Creek**	1.2 (1998-2013)	0.95 (2007-2013)			0.67 (2003)
Newport Bay	**Bassett Creek**	2.33 (2004-2013)		1.28 (2006-2013)	1.35/1.74 (2003- 2004)	2.08 (2003)
St. Martin River	**Birch Branch**	1.14 (2006-2013)	1.18 (2007-2013)	1.15 (2007-2013)		2.59 (1999)

1. Maryland Coastal Bays Program, volunteer monitoring program (1998-2013)
2. Maryland Department of Natural Resources Core Trend data
3. Maryland Coastal Bays Program, spring stream survey
4. U. S. Geological Survey, Estimates of the Loads of NO2+NO3 in the flow of Bassett Creek to the MD Coastal Bays
5. Maryland Department of Natural Resources

Summary

Elevated stream nitrate/nitrite concentrations are attributable to groundwater input as well as stormwater run off. Natural background concentrations of nitrate in streams is 0.6 mg/L with concentrations greater than 1.0 mg/L indicative of anthropogenic inputs (USGS 1999). Concentrations are above these thresholds for healthy streams may impact stream biota as well as contribute to total nitrogen loads in the bays. Continued monitoring will be needed to determine if concentrations/ inputs begin to change. Stream specific enrichment can be used to focus management actions to reduce eutrophication impacts to the bays.

References

U.S. Geological Survey, 1999, The Quality of Our Nation's Water – Nutrient and Pesticides, Circular 1225, 82 p.

Chapter 3.2

Maryland Biological Stream Survey Results for the Coastal Bays Watershed

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Abstract
To report overall stream health, freshwater fish and benthic macroinvertebrate indices of biotic integrity were calculated for all Maryland Biological Stream Survey and Maryland Stream Waders sites with adequate data. These indices of biotic integrity rate stream health according to ecological characteristics of fauna found in the sampled stream. Fish and benthic macroinvertebrate samples indicate most streams in the Coastal Bays are degraded but there are a few exceptions. Most fauna sampled were classified as pollution-tolerant. Benthic index of biotic inegrity results from both programs - 61 sites total - rated most sites as either poor (31%) or very poor (54%). Most of the remaining sites were rated fair (13%). One site was rated good by the benthic index of biotic integrity. Freshwater fish index results from 9 sites rated most sites as poor (33%) or very poor (44%), with 11% rated fair or good. Impacts to the biota of Coastal Bays streams are likely the result of physical habitat modification (e.g., ditching) and excess nutrients. Ditched streams generally have less habitat diversity and lower flows than minimally-altered streams in the Coastal Plain that retain a more natural wetland character.

The Maryland Biological Stream Survey
The Maryland Biological Stream Survey (MBSS) monitors freshwater streams throughout Maryland. Data are collected on physical habitat, water chemistry, and invertebrate and fish communities. Nine randomly-selected sites were sampled in the Coastal Bays watersheds in 2009. A total of 14 fish species were collected (Table 3.2.1), with species counts ranging from nine at one site in Newport Bay to no fish at two sites - one site in Newport Bay and one site in Chincoteague Bay. The average number of species among all Coastal Bays sites was 4.1 and the greatest number of individual fish per site (266) was sampled at a site in Newport Bay. The average number of fish per site among all Coastal Bays sites was 119. The dominant fish species was Eastern mudminnow, averaging 58 fish per site, while the largemouth bass was the rarest species (0.67 fish per site average). A list of fish species sampled in Coastal Bays streams by MBSS is below.

Eighty-seven taxa (mostly genera) of benthic macroinvertebrates were sampled at MBSS sites (Table 3.2.2). The number of taxa per site averaged 18.8 and ranged from eight to 32. Dominant taxa included isopods (Caecitodea sp., Crangonyx sp.); fingernail clams (Musculium sp.); midges (Orthocladius sp., Paratanytarsus sp.) and black flies (Simulium sp., Stegopterna sp.).

Table 3.2.1 Fish species sampled in MD Coastal Bays streams.

Species	Tolerance	Native or Introduced
American eel, *Anguilla rostrata*	NC	Native
Banded killifish, *Fundulus diaphanus*	NC	Native
Bluegill, *Lepomis macrochirus*	Tolerant	Introduced
Bluespotted sunfish, *Enneacanthus obesus*	NC	Native
Brown bullhead *Ameiurus nebulosus*	Tolerant	Native
Creek chubsucker, *Erimyzon oblongus*	NC	Native
Eastern mosquitofish *Gambusia holbrooki*	NC	Native
Eastern mudminnow, *Umbra pygmaea*	Tolerant	Native
Golden shiner, *Notemigonus crysoleucas*	Tolerant	Native
Largemouth bass, *Micropterus salmoides*	Tolerant	Introduced
Pirate perch, *Aphredoderus sayanus*	Tolerant	Native
Pumpkinseed, *Lepomis gibbosus*	Tolerant	Native
Redfin pickerel, *Esox americanus*	Tolerant	Native
Tessellated darter, *Etheostoma olmstedi*	Tolerant	Native

Management Objective: Healthy Stream Fauna

Indicator 1: Freshwater Fish Index >4
Indicator 2: Benthic Macroinvertebrate Index >4

Table 3.2.2 Benthic macroinvertebrate taxa sampled by Maryland Biological Stream Survey from Coastal Bays streams.

Taxon	Tolerant or sensitive	Taxon	Tolerant or sensitive
Agabus	NC	*Musculium*	Tolerant
Ancronyx	Tolerant	*Nanocladius*	Tolerant
Aspectrotanypus	Tolerant	*Oecitis*	Tolerant
Argia	Tolerant	*Ormosia*	NC
Bittacomorpha	NC	*Orthocladiinae*	Tolerant
Boyeria	NC	*Orthocladius*	Tolerant
Caecidotea	Tolerant	*Parachaetocladius*	Sensitive
Calopteryx	Tolerant	*Parametriocnemus*	Tolerant
Ceratopogonidae	NC	*Paraphaenocladius*	NC
Chaetocladius	Tolerant	*Paratanytarsus*	Tolerant
Cheumatopsyche	Tolerant	*Paratendipes*	NC
Clinotanypus	Tolerant	*Peltodytes*	Tolerant
Coenagrionidae	Tolerant	*Phaenopsectra*	Tolerant
Corynoneura	Tolerant	*Physa*	Tolerant
Crangonicyidae	Tolerant	*Pisidiidae*	NC
Crangonyx	NC	*Platycentropus*	NC
Cricotopus	Tolerant	*Polycentropus*	Sensitive
Cryptochironomus	Tolerant	*Polypedilum*	Tolerant
Dicrotendipes	Tolerant	*Potthastia*	Sensitive
Diplocladius	Tolerant	*Probezzia*	Sensitive
Dubiraphia	Tolerant	*Procambarus*	Sensitive
Dytiscidae	Tolerant	*Pseudolimnophila*	Tolerant
Enchytraeidae	Tolerant	*Ptilostomis*	Tolerant
Ferrissia	Tolerant	*Rheocricotopus*	Tolerant
Gammarus	Sensitive	*Rheotanytarsus*	Tolerant
Gomphus	Sensitive	*Simulium*	Tolerant
Gordiidae	Tolerant	*Spirosperma*	NC
Gyrinus	NC	*Stagnicola*	Tolerant
Helocombus	NC	*Stegopterna*	NC
Heloplectron	NC	*Stempellinella*	NC
Hydrobaenus	Tolerant	*Stygrobromus*	NC
Hydrochara	NC	*Synurella*	NC
Hydropsyche	Tolerant	*Tanypodinae*	Tolerant
Ironoquia	NC	*Tanytarsus*	Tolerant
Lepidostoma	Sensitive	*Thienemanniella*	Tolerant
Leptophlebiidae	Sensitive	*Thienemannimyia*	Tolerant
Limnephilidae	Sensitive	*Tipula*	NC
Limnodrilus	Tolerant	*Triaenodes*	NC
Lumbriculidae	NC	*Tribelos*	Tolerant
Lype	NC	*Tubificidae*	Tolerant

Maccaffertium	Sensitive	*Xylotopus*	NC
Menetus	NC	*Zavrelimyia*	Tolerant
Micropsectra	Tolerant		

Monitoring Programs:
Nine stream sites were sampled in the Coastal Bays watersheds during 2009 as part of the MBSS. Fish, benthic macroinvertebrate and water samples were collected and physical habitat was assessed according to methods described in Stranko (2008) and Boward and Friedman (2000). To report overall stream health, fish and benthic macroinvertebrate indices of biotic integrity (IBI) were calculated for all sites that had adequate data. Also, in 2009, 2011, and 2012, spring benthic macroinvertebrate samples were collected at 52 sites by volunteers as part of DNR's Stream Waders Program. A family level benthic IBI was calculated for these sites. Table 3.2.3 summarizes MBSS and Stream Waders sampling in Coastal Bays watersheds.

Table 3.2.3 Summary of Maryland Biological Stream Survey, MBSS, and Stream Waders sampling in the Coastal Bays between 2007 and 2013.

Site Type	Year	Number of Sites	Site Selection Method	Watersheds Sampled
MBSS	2009	9	Non-random (5) and random (4)	Chincoteague Bay, Newport Bay
Stream Waders	2009	29	Non-random	Chincoteague Bay, Isle of Wight Bay, Newport Bay
Stream Waders	2011	16	Non-random	Assawoman Bay, Chincoteague Bay, Isle of Wight Bay, Newport Bay, Sinepuxent Bay
Stream Waders	2012	7	Non-random	Chincoteague Bay, Newport Bay, Sinepuxent Bay

Management Objective: Healthy Stream Fauna

MBSS Indicator 1: Fish IBI (thresholds described below)
MBSS Indicator 2: Invertebrate IBI (thresholds described below)

The MBSS fish and benthic macroinvertebrate IBIs rate stream health according to ecological characteristics of each assemblage (Roth et. al 2000; Southerland et. al 2005). Table 3.2.4 explains the ranges of the IBI and the corresponding narrative stream health ratings. Reference conditions for the Coastal Bays

Table 3.2.4 Stream health ratings and associated IBI thresholds.

Good (IBI score 4.0 – 5.0)	Comparable to reference streams considered to be minimally impacted
Fair (IBI score 3.0 – 3.9)	Comparable to reference conditions, but some aspects of biological integrity may not resemble the qualities of minimally-impacted streams
Poor (IBI score 2.0 – 2.9)	Significant deviation from reference conditions, with many aspects of biological integrity not resembling the qualities of minimally-impacted streams.
Very Poor (IBI score 1.0 – 1.9)	Strong deviation from reference conditions, with most aspects of biological integrity not resembling the qualities of minimally-impacted streams.

Analyses

The fish index of biotic integrity (FIBI) were calculated for the nine MBSS sites in the Coastal Bays watersheds. Benthic macroinvertebrate IBIs were calculated for 61 sites (9 MBSS and 52 Stream Waders).

Indicators of Stream Condition

FIBI results from five sites ranged from 1.0 (very poor) to 4.0 (good) (Figure 3.2.1). Benthic macroinvertebrate IBI (BIBI) values ranged from 1.0 (very poor) to 4.7 (good) (figure 3.2.2). The percentage of sites in each IBI category is shown in Figure 3.2.5.

The following tables list conditions (based on FIBI and BIBI) for MBSS and Stream Waders sites in the Coastal Bays watersheds. Stream Waders sites have numbers only and the last four digits indicate the year the sample was collected. MBSS sites contain either a county or watershed code. A blank stream name indicates that the stream name is unknown. NA in the Benthic IBI and Fish IBI Stream Condition columns indicate no data collected.

Assawoman Bay – A single Stream Waders sample was taken in the Assawoman Bay watershed. The Benthic IBI for this site was 1.29 (very poor). There were no MBSS data available from this watershed (Table 3.2.5).

Table 3.2.5 Assawoman Bay stream stations and fish and benthic indicator of biotic integrity (IBI) results.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0689-02-2011	Back Creek at Catepillar Road	1.29	very poor	NA	NA

Isle of Wight /St. Martin River – Twelve sites were sampled by Stream Waders volunteers in the Isle of Wight Bay watershed. Eight sites were rated very poor by the BIBI and three sites were rated poor (Table 3.2.6). Only one site (Birch Branch) was rated fair. There were no MBSS data available from this watershed.

Table 3.2.6 Isle of Wight Bay stream stations and fish and benthic indicator of biotic integrity (IBI) results.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0690-02-2009	Turville Creek UT	1.00	very poor	NA	NA
0692-01-2009	Cemetery Creek	1.00	very poor	NA	NA
0691-03-2009	Middle Branch	1.29	very poor	NA	NA
0692-03-2009	Slab Bridge Creek	1.29	very poor	NA	NA
0687-01-2011	Jake Gut	1.29	very poor	NA	NA
0690-01-2009	Crippen Creek	1.57	very poor	NA	NA
0691-01-2009	Middle Branch	1.57	very poor	NA	NA
0692-04-2009	Carey Branch	1.57	very poor	NA	NA
0691-02-2011	Middle Branch	2.14	poor	NA	NA
0691-04-2009	Church Branch	2.14	poor	NA	NA
0691-02-2009	Birch Branch	2.71	poor	NA	NA
0691-01-2011	Birch Branch	3.29	fair	NA	NA

Sinepuxent – Three sites were sampled by Stream Waders volunteers in the Sinepuxent Bay watershed and all were rated very poor by the BIBI (Table 3.2.7).

Table 3.2.7 Sinepuxent Bay stream stations and fish and benthic indicator of biotic integrity (IBI) results.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0681-01-2011	Eagles Nest Creek	1.29	very poor	NA	NA
0681-03-2011	Decatur Ditch	1.29	very poor	NA	NA

Newport – Seven MBSS and 11 Stream Waders sites were sampled in the Newport Bay watershed. Both FIBIs and BIBIs reflect steam conditions ranging from very poor to fair (Table 3.2.8). The two FIBIs reflect fair and poor conditions in Kitts Branch and Bottle Branch, respectively. Ayer Creek, Bassett Creek and Massey Branch all were rated fair by either a BIBI or a FIBI.

Table 3.2.8 Newport Bay stream stations and fish and benthic indicator of biotic integrity (IBI) results.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0685-01-2009	Bottle Branch	1.00	very poor	NA	NA
0683-03-2009	Poplartown Branch	1.86	very poor	NA	NA
NEWP-103-R-2009	Tukesburgh Branch	1.86	very poor	1.67	very poor
0685-01-2011	Hudson Branch	1.86	very poor	NA	NA
NEWP-125-B-2009	Marshall Creek UT2	2.14	poor	1.00	very poor
NEWP-128-B-2009	Marshall Creek UT3	2.14	poor	1.00	very poor
NEWP-112-B-2009	Ayer Creek	2.14	poor	3.33	fair
NEWP-111-B-2009	Kitts Branch	2.43	poor	2.67	poor
0682-02-2011	Icehouse Branch	2.71	poor	NA	NA
0683-02-2009	Porter Creek	2.71	poor	NA	NA
NEWP-111-R-2009	Massey Branch	3.00	fair	2.33	poor
NEWP-115-B-2009	Kitts Branch	3.00	fair	2.33	poor
0682-01-2009	Marshall Creek UT	3.00	fair	NA	NA
0683-01-2009	Bassett Creek	3.29	fair	NA	NA
0682-01-2011	Massey Branch	3.29	fair	NA	NA
0683-01-2011	Bassett Creek	3.86	fair	NA	NA

Chincoteague - Two MBSS and 25 Stream Waders sites were sampled in the Chincoteague Bay watershed. FIBIs reflect very poor to good conditions in Waterworks Creek UT and Little Mill Creek, respectively (Table 3.2.9). The BIBI in Little Mill Creek indicates good conditions as well. This is the only stream in this report to be rated good either the FIBI or the BIBI.

Table 3.2.9 Chincoteague Bay stream stations and fish and benthic indicator of biotic integrity (IBI) results.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0671-02-2009	Hancock Creek	1.00	very poor	NA	NA
0675-03-2009	Brimers Gut	1.00	very poor	NA	NA
0666-02-2012	Pusey Branch	1.00	very poor	NA	NA
0671-01-2009	Riley Creek	1.29	very poor	NA	NA
0679-01-2009	Robins Creek	1.29	very poor	NA	NA
0679-01-2011	Robins Creek	1.29	very poor	NA	NA
0672-01-2009	Bunn Ditch	1.57	very poor	NA	NA

0674-01-2009	Pikes Creek UT	1.57	very poor	NA	NA
0675-01-2009		1.57	very poor	NA	NA
CHIN-109-R-2009	Waterworks Creek UT	1.57	very poor	1.00	very poor
0680-01-2009	Waterworks Creek	1.86	very poor	NA	NA
0672-01-2011	Little Mill Creek	1.86	very poor	NA	NA
0678-01-2011	Paw Paw Creek	1.86	very poor	NA	NA
0671-01-2011	Purnell Bay UT	2.14	poor	NA	NA
0674-01-2011	Scarboro Creek	2.14	poor	NA	NA
0672-03-2009	Little Mill Creek	2.14	poor	NA	NA
0674-03-2009	Pikes Creek	2.43	poor	NA	NA
0675-02-2009	Brimers Gut	2.43	poor	NA	NA
0676-01-2011	Tanhouse Creek	2.71	poor	NA	NA
0671-03-2009	Powell Creek	2.71	poor	NA	NA
0672-02-2009	Little Mill Run	2.71	poor	NA	NA
0674-02-2009	Pikes Creek	2.71	poor	NA	NA
0675-01-2011	Brockanorton Bay UT	3.29	fair	NA	NA
CHIN-105-R-2009	Little Mill Creek	4.71	good	4.00	good

Summary

Fish and benthic macroinvertebrate data from MBSS and Stream Waders sampling suggest that most streams in the Coastal Bays are degraded. Most taxa from both assemblages are pollution-tolerant. Benthic IBIs from MBSS and Stream Waders samples rated most sites as either poor (15%) or very poor (75%) with the remaining sites (10%) rated fair. Fish IBIs from MBSS samples rated most sites as poor (14%) or very poor (43%), with 43% rated fair.

Impacts to the biota of Coastal Bays streams likely result from physical habitat modification (e.g., ditching) and nutrient enrichment. Ditched streams generally have less habitat diversity and lower flows than minimally-altered streams in the Coastal Plain that retain their more natural wetland character. For more information on the status of physical and water chemistry please see the MBSS Round Three Report (http://www.dnr.state.md.us/streams/R3ReportIntro.asp).

Acknowledgements

DNR would like to thank all of the Stream Waders volunteers and MBSS crew members who helped to collect data in the Coastal Bays.

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Figure 3.2.1 Fish Index of Biotic Integrity (IBI) for freshwater streams of the Coastal Bays watershed sampled in 2001. Only streams with watersheds greater than 300 km^2 were calculated for fish IBI.

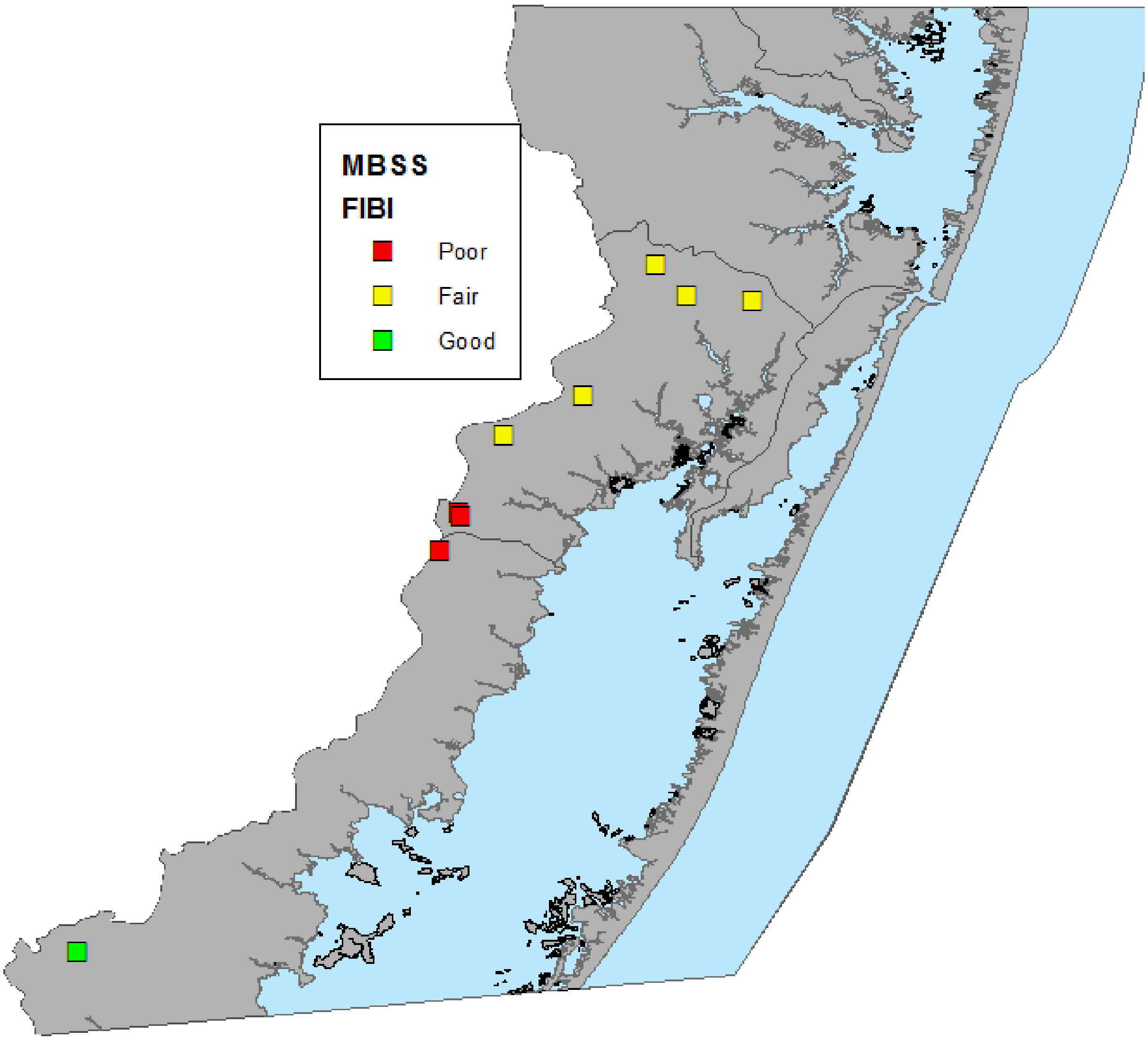


Figure 3.2.2 Benthic Index of Biotic Integrity (IBI) for freshwater streams of the Coastal Bays watershed sampled in 2009, 2011, 2012.

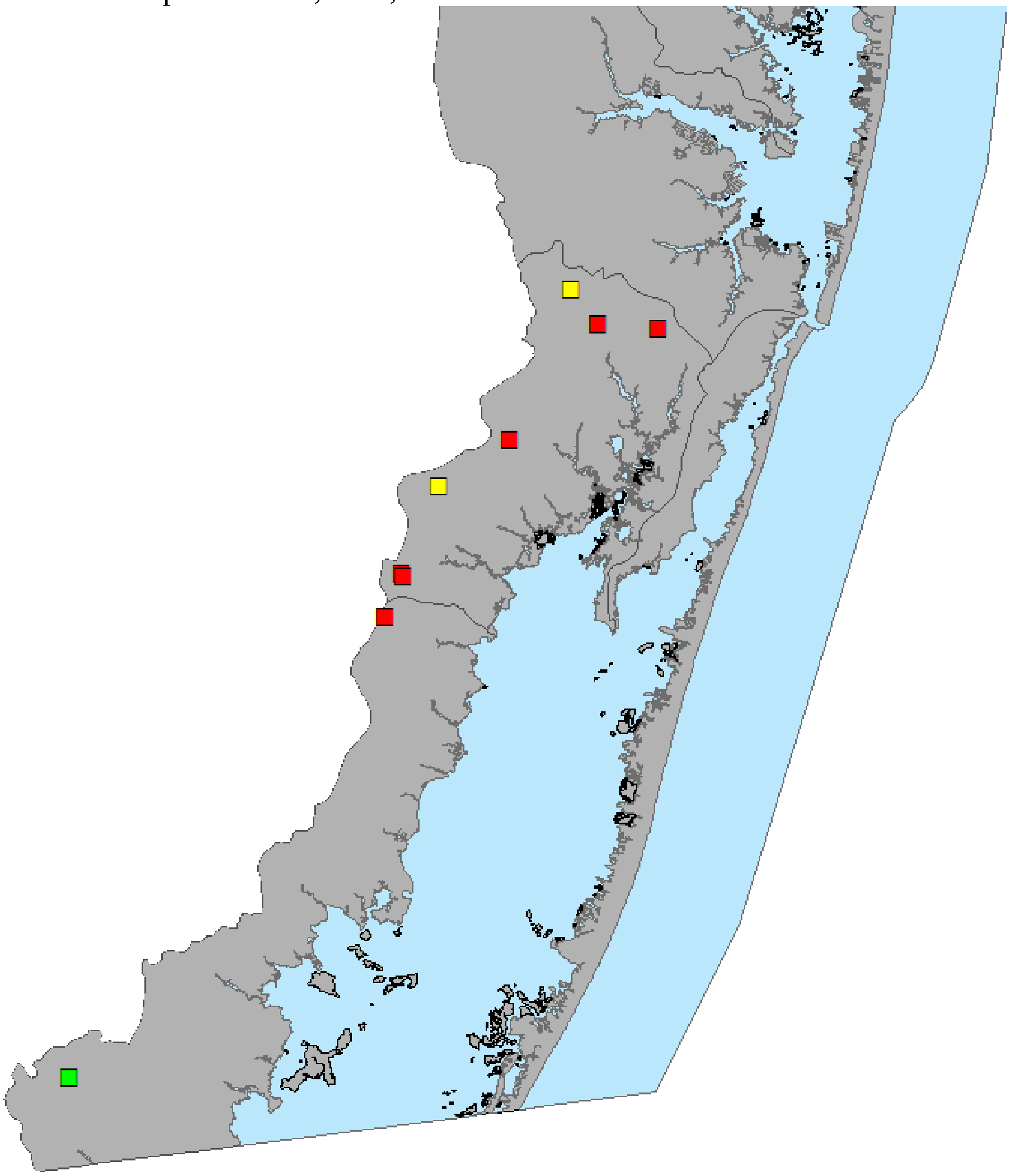


Figure 3.2.3 Streamwader results 2009, 2011 and 2012

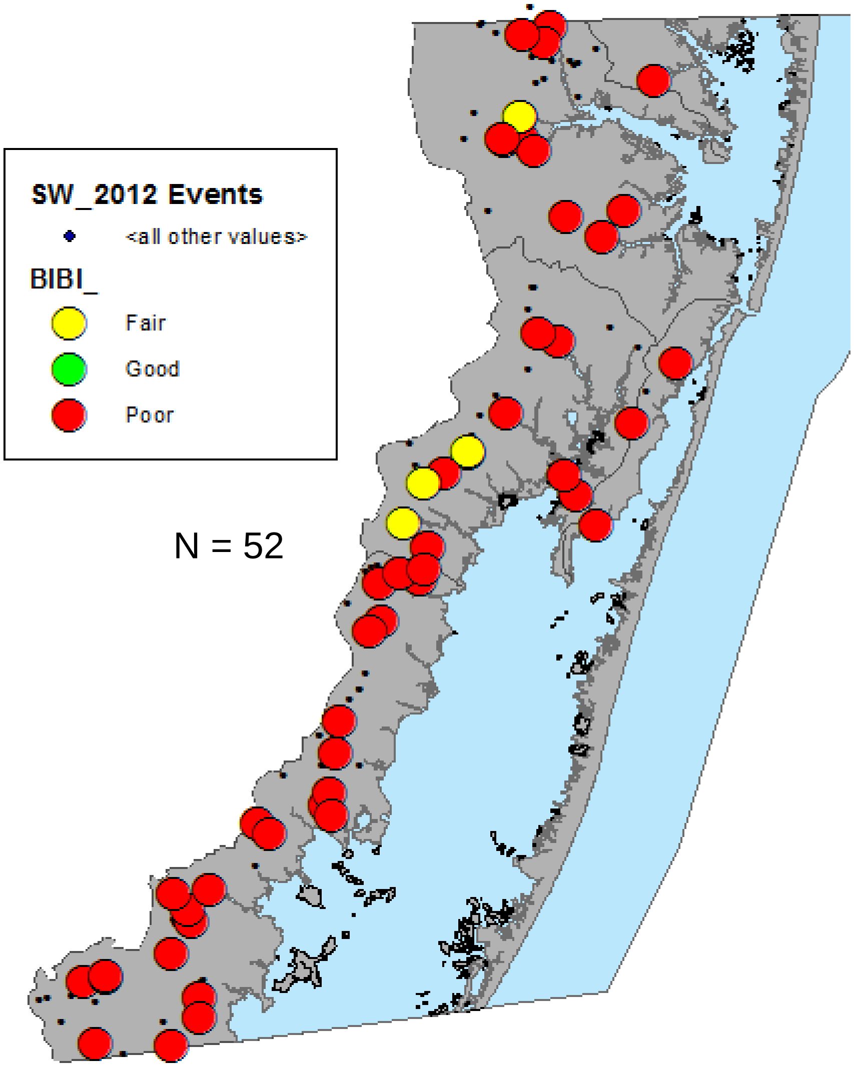
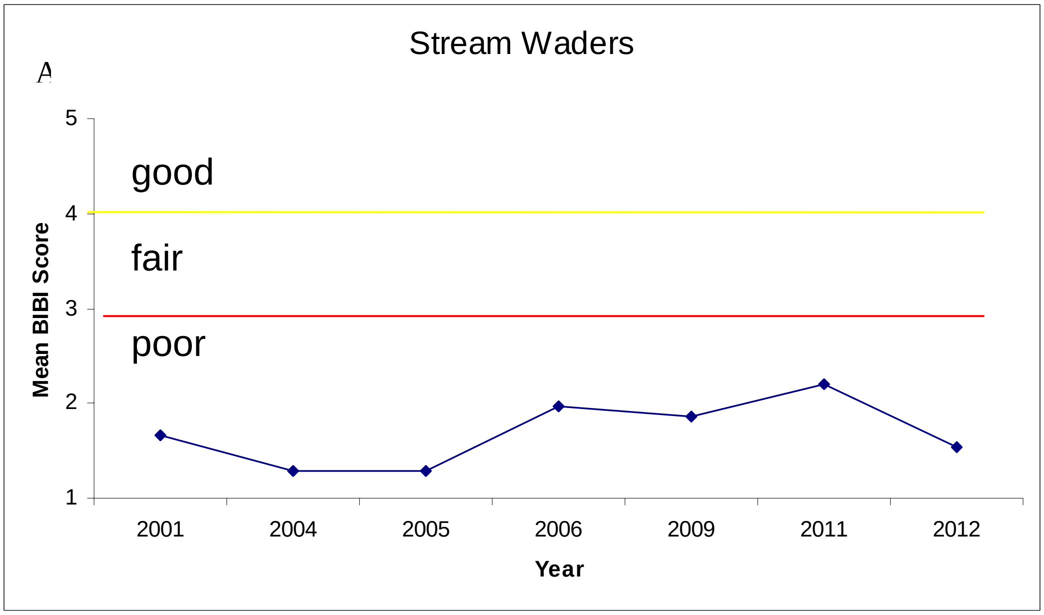


Figure 3.2.4 Streamwader mean abundance based on the benthic index of biotic integrity scores: 2001 – 2012. B. Percent of stream health that was ranked poor, fair and good.



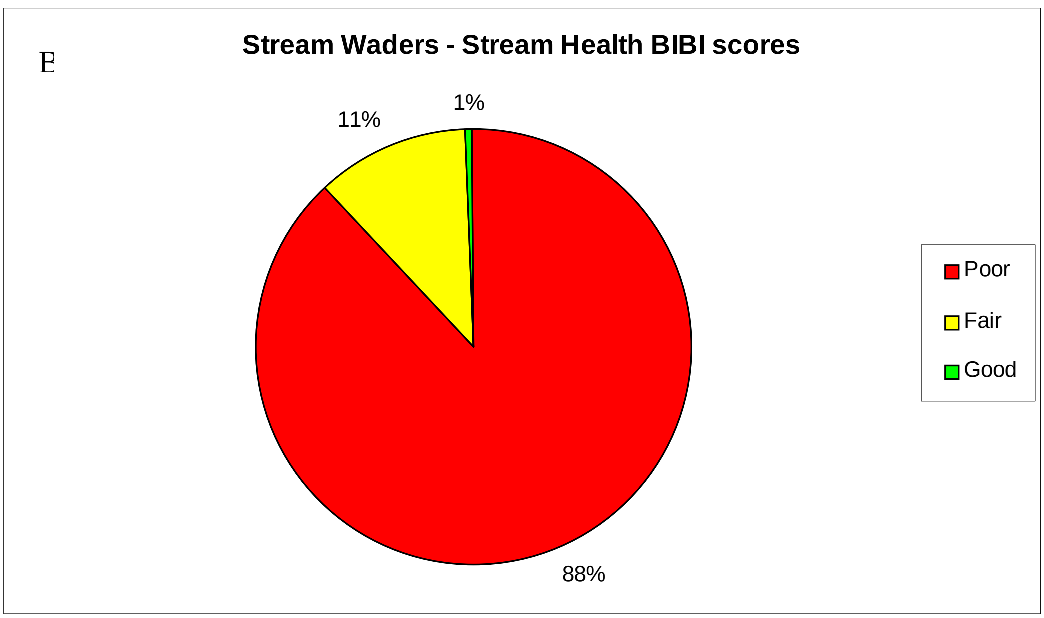
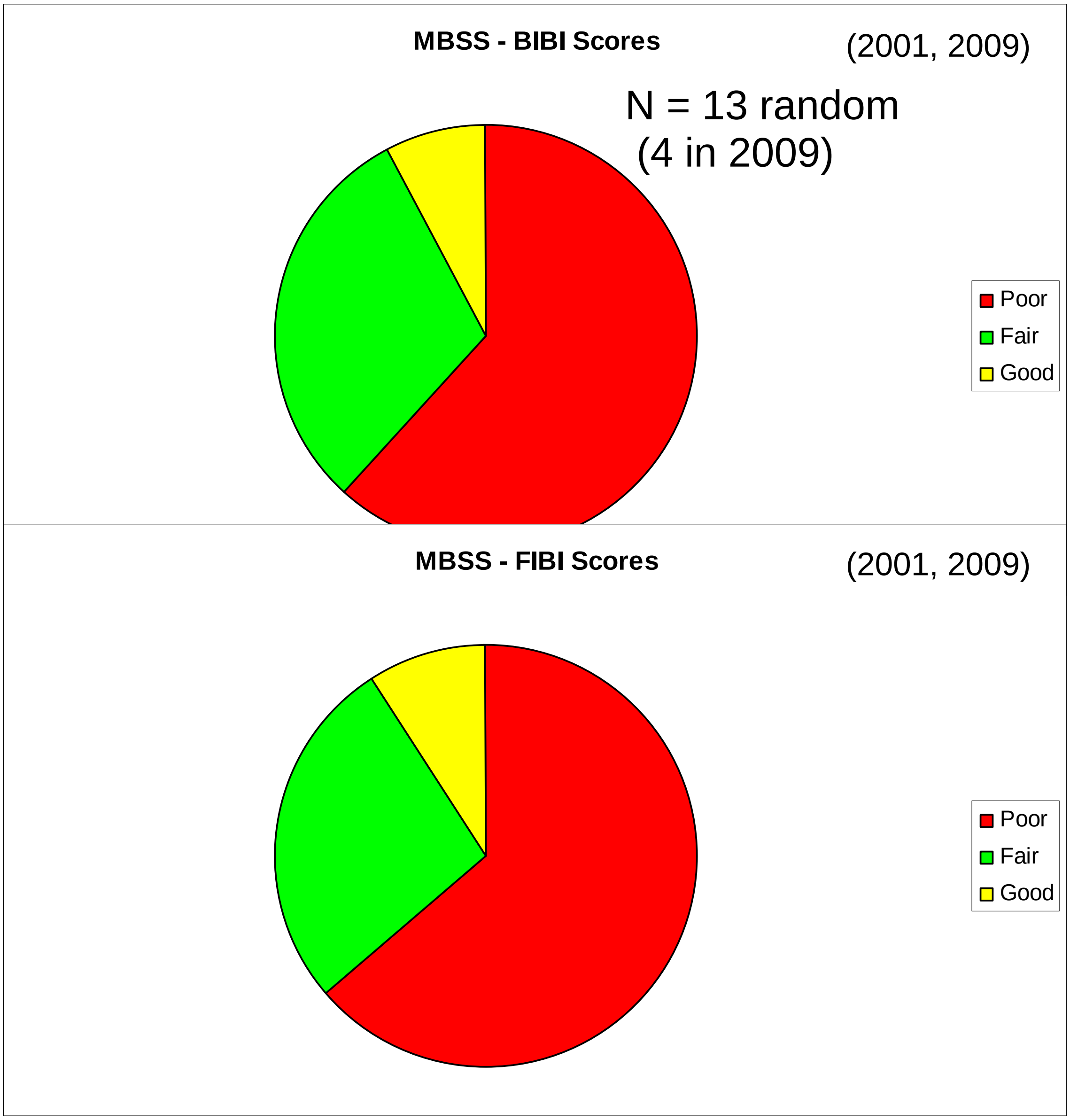


Figure 3.2.5 A.) Percentages of sampling sites falling within each of the Fish Index of Biotic Integrity cut-off points for 2001 MBSS sampling data. B.) Percentages of sampling sites falling within each of the Benthic Index of Biotic Integrity cut-off points for 2001 MBSS sampling data.



Chapter 3.3

Trends in Freshwater Benthic Macroinvertebrate Communities in Maryland's Coastal Bays

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Abstract
Current freshwater benthic macroinvertebrate community conditions help determine long-term water quality and habitat trends in Newport and St Martin watersheds. Samples from two of the St Martin streams (Bishopville Prong and South Branch) indicated a strong improvement in water quality from the very poor to fair range. Both sites showed an improvement in taxa number, as well as in biotic and diversity indices and South Branch showed an improvement in Percent EPT (**E**phemeroptera, **P**lecoptera, **T**richoptera). The third stream in the St Martin watershed, Birch Branch, has been not been sampled since 2001 due to inadequate substrate to sample. During the six years it was sampled there was no significant trend in the fair water quality. Streams in the Newport watershed showed slight improvements in diversity index and taxa number yet the biotic index showed decline over the past decade. Bottle Branch showed a slight improvement in percent EPT; however, the water quality is still in the poor/fair range. The Trappe Creek station showed a moderate improvement in water quality from the poor to the fair range with both the taxa number and diversity index values improving. Overall the conditions are improving but still remain fairly degraded in the Coastal Bays watersheds.

Introduction
Streams carry nutrients,sediments, and pollution from the landscape and groundwater to the bays. Thus, the ecological integraty of streams is critical to maintaining the ecological quality of the Coastal Bays. The benthic community is particulary useful for assessment because the aquatic animals are, over a period of time,exposed to the range of physical and chemical stressors present in a stream. To report overall stream health, researchers use the diversity and abundance of benthic organisms. Benthic community structure and abundance, as well as water quality, are monitored at four sites in the St. Martin River and Trappe Creek to determine population trends related to eutrophication.

Data Sets
Freshwater benthic macroinvertebrate data were collected by Maryland Department of Natural Resources (DNR) annually since 1978 as part of Maryland's core water quality monitoring program (Friedman, 1996). Core site trend data were collected and analyzed at each site as a measure of water and habitat quality. This contrasts with Maryland biological stream survey data (Chapter 3.2), which utilized multiple parameters to assess the health of the entire stream. Data were collected at two non-tidal stations (Birch Branch, South Branch) and three tidal freshwater stations (Bottle Branch, Bishopville Prong, Trappe Creek) to determine long-term water quality trends. Three of these stations were tributaries to the St. Martin River. They were on Birch Branch (BIH0009), Bishopville Prong (BSH0030), and South Branch (SBR0022; also known as Church

Branch) (Figure 3.3.1). One of the stations was on the headwaters of Trappe Creek (TRC0059) and the other was on a tributary to Trappe Creek named Bottle Branch (BOB0001) (Figure 3.3.1).

Management Objective: Improving trends for stream health

Indicator: Community trend analysis (see below)

Analyses

Four benthic macroinvertebrate community measures were calculated: taxa number, Shannon-Weiner Diversity index, Modified Hilsenhoff biotic index, and percent Ephemeroptera, Plecoptera, Trichoptera (%EPT) and analyzed using non-parametric statistics (Friedman, 1996).

Results

St. Martin River – Benthic macroinvertebrate communities indicated a strong improvement in water quality from the very poor to fair range at the Bishopville Prong (BSH0030) and the South Branch (SBR0022) stations (Figure 3.3.2). Both sites showed an improvement in taxa number, biotic and diversity indices with South Branch also showing an improvement in %EPT. The benthic community indicated no significant trend in fair water quality at Birch Branch (BIH0009) (Figure 3.3.2).

Newport Bay – Bottle Branch showed a slight improvement in the %EPT with the values improving from the very poor to the poor range and the water quality at this site is still in the poor/fair range. Trappe Creek station showed a moderate improvement in water quality from the poor to the fair range with both the taxa number and diversity index values improving.

The benthic macroinvertebrate community at Bottle Branch (BOB0001) showed a slight improvement with an improving trend in %EPT. At the Trappe Creek (TRC0059) station both taxa numbers and diversity index values showed improvement.

Both sites showed a decline in the Hilsenhoff biotic index

Summary

Samples from the streams in the St. Martin watershed indicated a strong improvement in water quality from the very poor to fair range at the Bishopville Prong and the South Branch stations. Both sites showed an improvement in taxa number, as well as in biotic and diversity indices and South Branch showed an improvement in %EPT. Streams in the Newport watershed show mixed results with small improvements in up to three of the indicators but declines in the biotic index.

References

Friedman, E. 2009. Benthic macroinvertebrate communities at Maryland's Core/Trend Monitoring Stations: Water Quality Status and Trends CBWP-MANTA-MN-09-1. Maryland Department of Natural Resources, Annapolis, MD.

Figure 3.3.1 Locations of long-term macroinvertebrate monitoring stations in the Coastal Bays.

Figure 3.3.2 Trends in freshwater macroinvertebrate community over time in three tributaries of the St. Martin River. Cut-off points and ranking categories were developed through an amalgamation of four commonly used diversity indices (see text). The biotic index score shown here is the modified Hilsenhoff biotic index. Birch Branch and South Branch are both non-tidal stations.

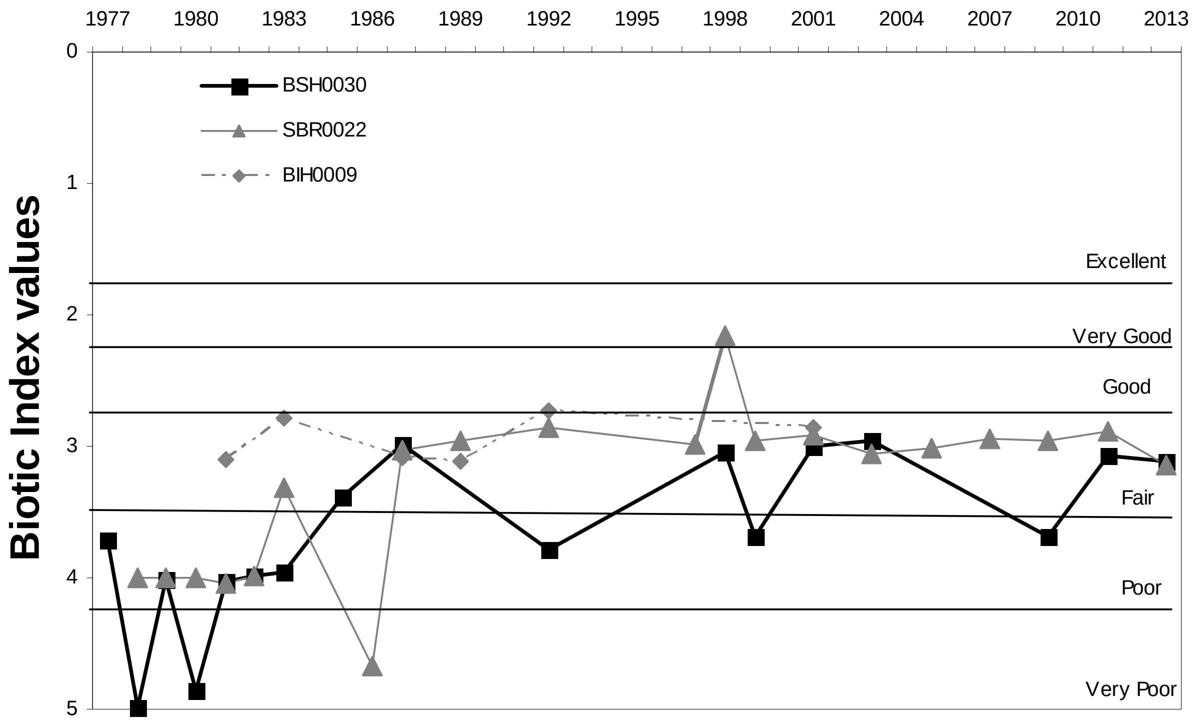
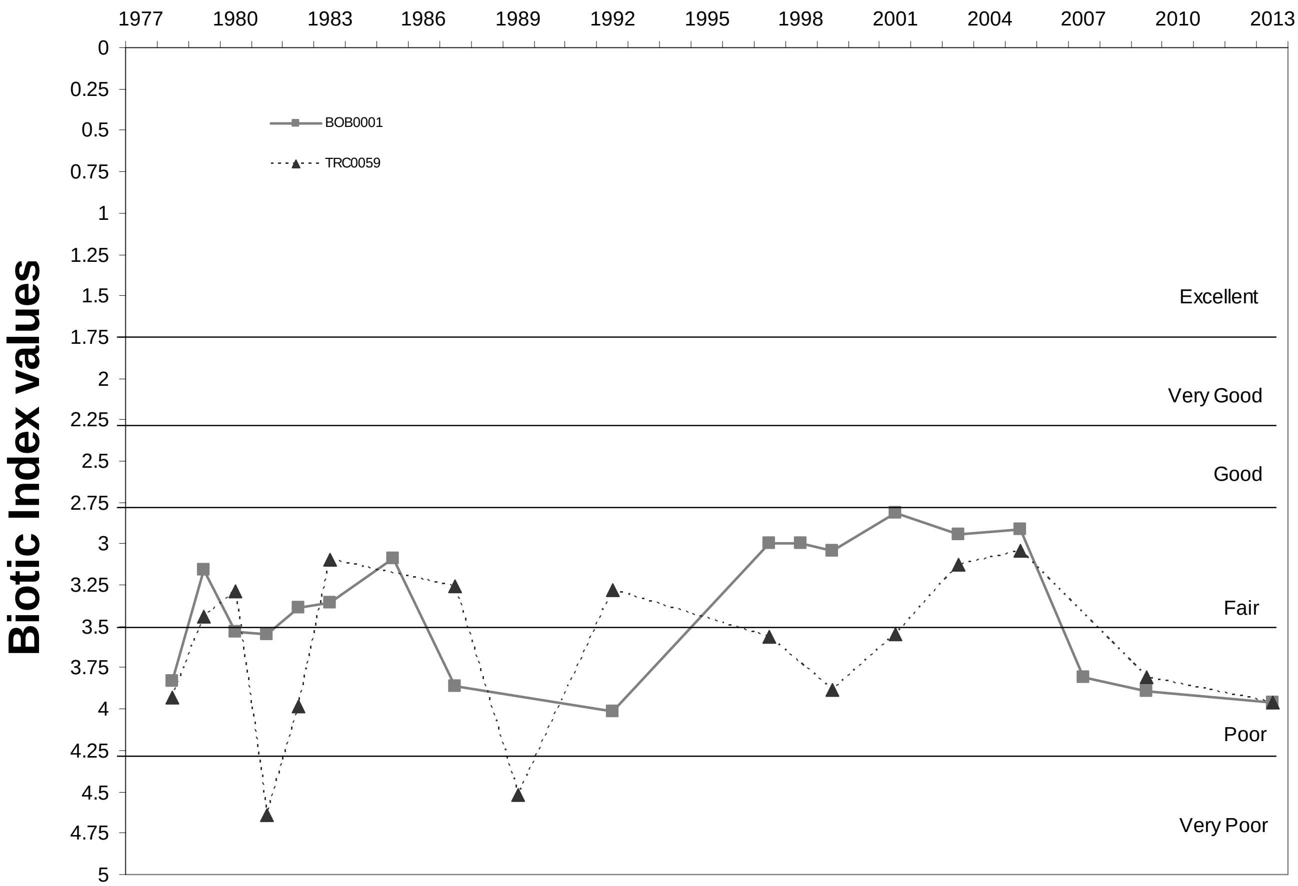


Figure 3.3.3 Trends in freshwater macroinvertebrate community over time in two tributaries of Newport Bay. Cut-off points and ranking categories were developed through an amalgamation of four commonly used diversity indices (see text).The biotic index score shown here is the modified Hilsenhoff biotic index.



Chapter 4.1

Nutrient status and trends in the Maryland Coastal Bays

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Abstract
Nutrient data was analyzed from 87 stations for current status (total nitrogen total phosphorus, and ammonium) and 60 sites for long-term trends (same nutrients as status as well as nitrate-nitrite and orthophosphate). Assawoman Bay, St. Martin River, northern Isle of Wight Bay, and Newport Bay were severely enriched with nitrogen while Sinepuxent and Chincoteague bays had the lowest total nitrogen concentrations. Phosphorus enrichment was widespread, exceeding water quality thresholds at 95% of stations. Ammonium concentrations exceeded seagrass thresholds at 57% of sites and were potentially lethal at 15-22% of sites. Ammonium concentrations were highest in the Virginia portion of Chincoteague Bay and in tributaries watershed-wide. Combined linear and non-linear trends analysis detected 152 unique significant trends among all parameters and stations (50%). Most trends were improving; only 20 significant degrading trends were found (7%). Overall nutrient levels in the Maryland Coastal Bays are fair to poor with generally improving trends since 1999.

Introduction

Nutrient over-enrichment is a major threat to the Coastal Bays. Nutrients can enter the water column from a wide range of point and non-point sources. Non-point sources include agriculture (fertilizer and animal waste), septic systems, legacy groundwater, and natural sources (wetlands, marshes, and forests). Atmospheric deposition is another non-point source that can bring in nutrients from outside the watershed. Some non-point source inputs are often sporadic or ephemeral, as when a storm event causes large amounts of run-off, while others such as groundwater are more constant inputs. Non-point nutrient inputs are the major sources of nitrogen and phosphorus to the Coastal Bays. Point sources, such as sewage treatment plants, are estimated to account for only 4% of the total nutrient inputs. Total nitrogen (TN) and total phosphorus (TP) were used as indicators to reduce variability associated when measuring dissolved nutrients only. Increases in ammonium (NH_4) at relatively low concentrations have been associated with adverse effects on seagrasses (also known as submerged aquatic vegetation or SAV) (van Katwijk et al. 1997; Van der Heide et al. 2008). Van Katwijk showed concentrations of 3μM (9μM application) did not show toxic effects but at a concentration of 10μM (25μM application treatment) plants did exhibit toxic impacts. Ammonium toxicity effects were more pronounced in plants grown on sand and at higher temperatures (20^{o}C) as found in the Coastal Bays.

Data Sets

Three separate but comparable water quality monitoring programs operate in the Coastal Bays (see Chapter 1.1). These programs are conducted by the Maryland Department of Natural Resources (DNR), the National Park Service at Assateague Island National Seashore (ASIS), and the Maryland Coastal Bays Program (MCBP) volunteer monitors. Figure 4.1.1 shows the locations of each station monitored between 2007 and 2013. A number of the same stations are sampled by two different programs (DNR and MCBP); however, the volunteer program samples more frequently. These provide useful quality assurance checks between monitoring programs, and may serendipitously result in better temporal coverage when sampling dates are not simultaneous. A full list of nutrient parameters monitored by ASIS and DNR is reported in the Maryland Coastal Bays Program Eutrophication Monitoring Plan (Wazniak 1999).

Management Objective: To achieve bay water concentrations of nutrients that meet seagrass thresholds.

Nitrogen Indicators:	TN = 0.65 mg/L seagrass health TN = 1.0 mg/L eutrophic
Phosphorus Indicators:	TP = 0.037 mg/L seagrass health TP = 0.1 mg/L eutrophic
Ammonium Indicators:	NH_4 = 2µM = 0.028 mg/L N as NH4 NH_4 = 4µM = 0.056 mg/L N as NH4 seagrass health

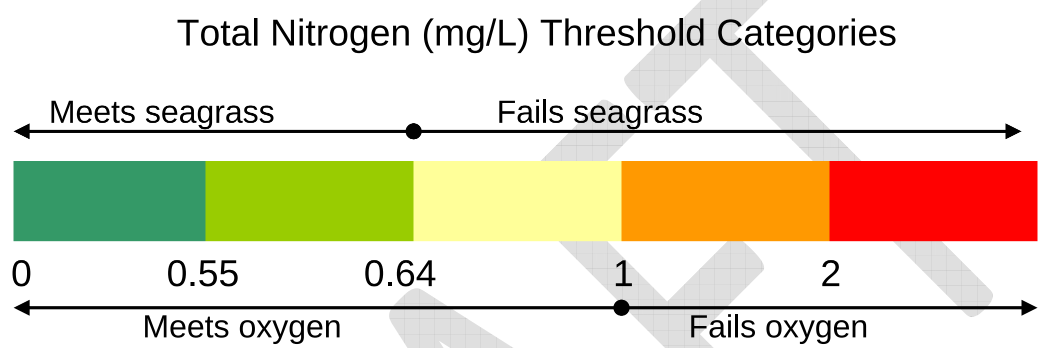
Analyses

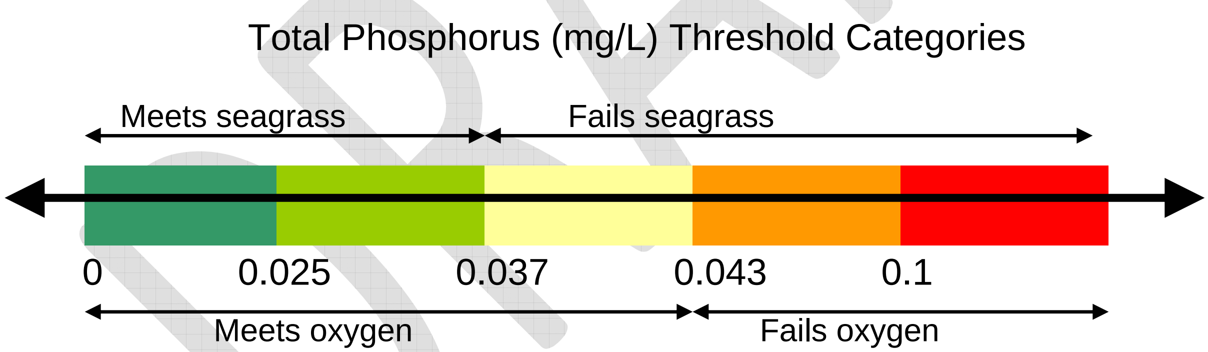
Status

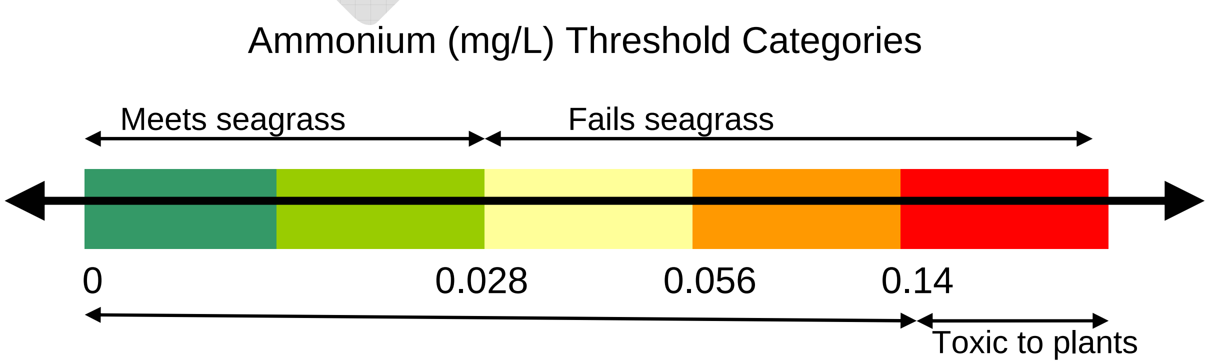
Median concentrations of TN, TP, and NH_4 were determined for rolling three-year periods between 2007-2013 for each DNR and ASIS monitoring station. Where data were available for specific 3-year periods, equivalent analyses were performed for MCBP stations (Figure 4.1.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed TN and TP threshold categories based on living resources indicators, most notably seagrass (Stevenson et al 1993) (Table 4.1.1). The NH_4 threshold of 4uM was suggested by Pat Glibert (pers. comm.) as harmful to seagrass health. Data from all months were used for TN and TP analyses, while data from only the seagrass growing season (April – October) were used for NH_4 analyses. Using a non-parametric Wilcoxon sign-rank test, median values were compared to threshold upper and lower boundaries. Medians that were significantly different than the boundary values at $p<0.01$ were considered statistically significant overall. Results are presented for all 3-year periods, with discussion focused on the most recent (2011-13).

Table 4.1.1 Threshold category values for TN, TP, and NH_4 in the Maryland Coastal Bays. Upper cutoff values are shown; lower cutoff values are the values from the previous category, forming category bounds for hypothesis testing. Bolded values are living resources indicator values as mandated by STAC.

Threshold criteria category	TN upper boundary value	TP upper boundary value	NH_4 upper boundary value
Better than seagrass objective	0.55 mg/L	0.025 mg/L	
Meets seagrass objective	**0.64 mg/L**	**0.037 mg/L**	0.028 mg/L
Does not meet seagrass objective	**1 mg/L**	0.043 mg/L	0.056 mg/L
Does not meet STAC objectives	2 mg/L	**0.1 mg/L**	
Does not meet any objectives	> 2 mg/L	> 0.1 mg/L	> 0.126 mg/L







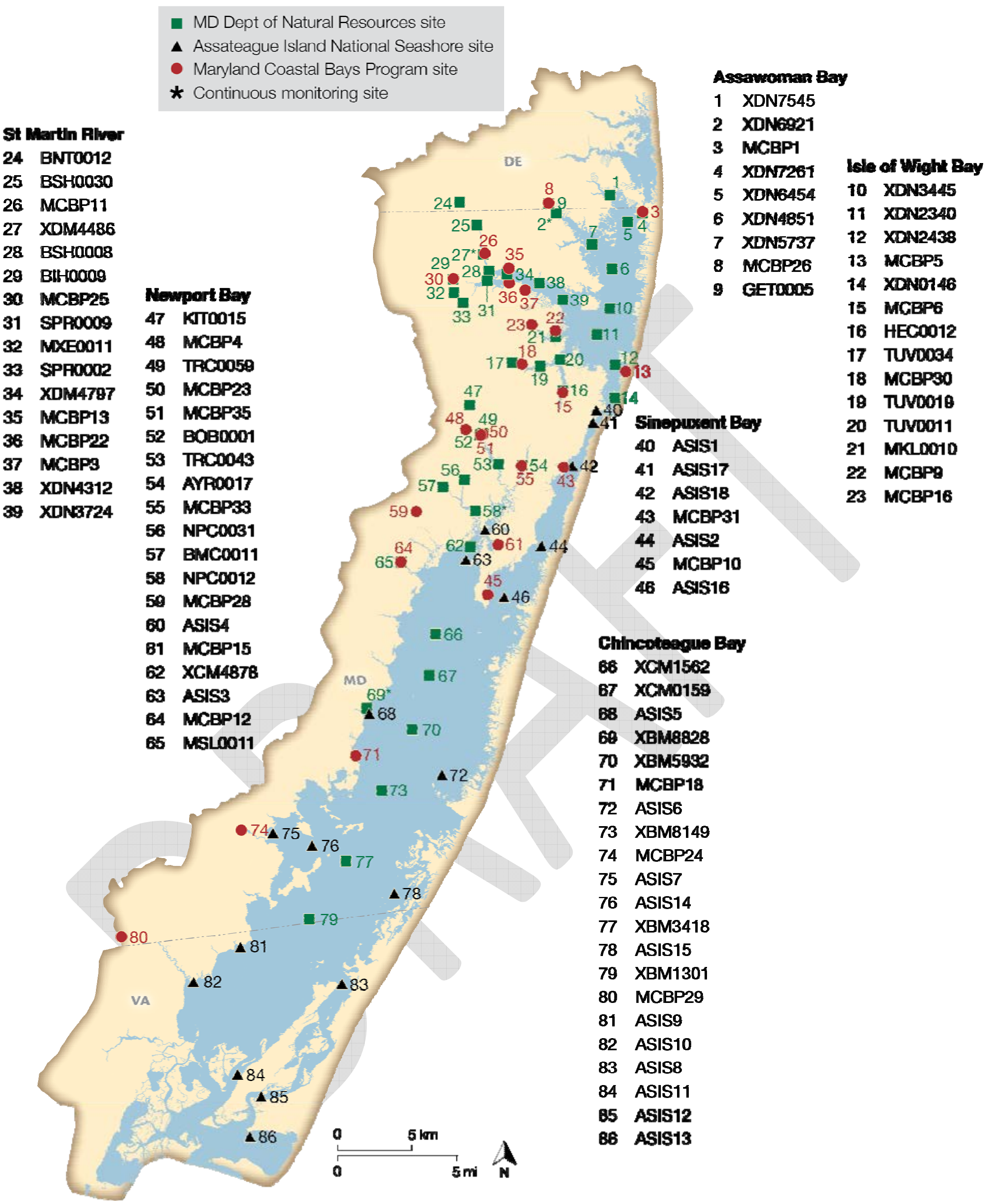


Figure 4.1.1 Water quality monitoring station locations.

<u>*Trends*</u>
Trend analyses were used to compare the effect of time on water quality parameters, including TN and TP, plus the dissolved parameters ammonium (NH_4), nitrate-nitrite (NO_{23}), and orthophosphate (PO_4). Linear and non-linear analyses were performed on all stations that have been sampled continuously since 1999 (since 2001 for a subset of DNR stations). At least 10 continuous years of data are required for trend analyses. No MCBP stations met that criterion, so trends were not determined for those stations. The Seasonal Kendall test was used to identify linear trends, and Sen's slope estimator was used to estimate the magnitude of change over time when a significant trend was present (Ebersole et al. 2002; Hirsch et al. 1982; Van Belle and Hughes 1984). For all trend tests, a significance level of $p<0.01$ was used to achieve the highest possible power. Where no linear trend was detected, non-linear trend analysis was performed to identify if trend direction reversals occurred during the analysis period (Wazniak et al. 2007).

Results: Status of nutrient concentrations
Rolling three year statuses of TN, TP, and NH_4 concentrations in each Coastal Bays segment were examined. Results focus on the most recent time-period (2011-2013). Figure 4.1.2 maps the status of each parameter for the most recent 3-year period, 2011-13. The status of NH_4 was determined to investigate potential impacts on seagrass growth in the bays.

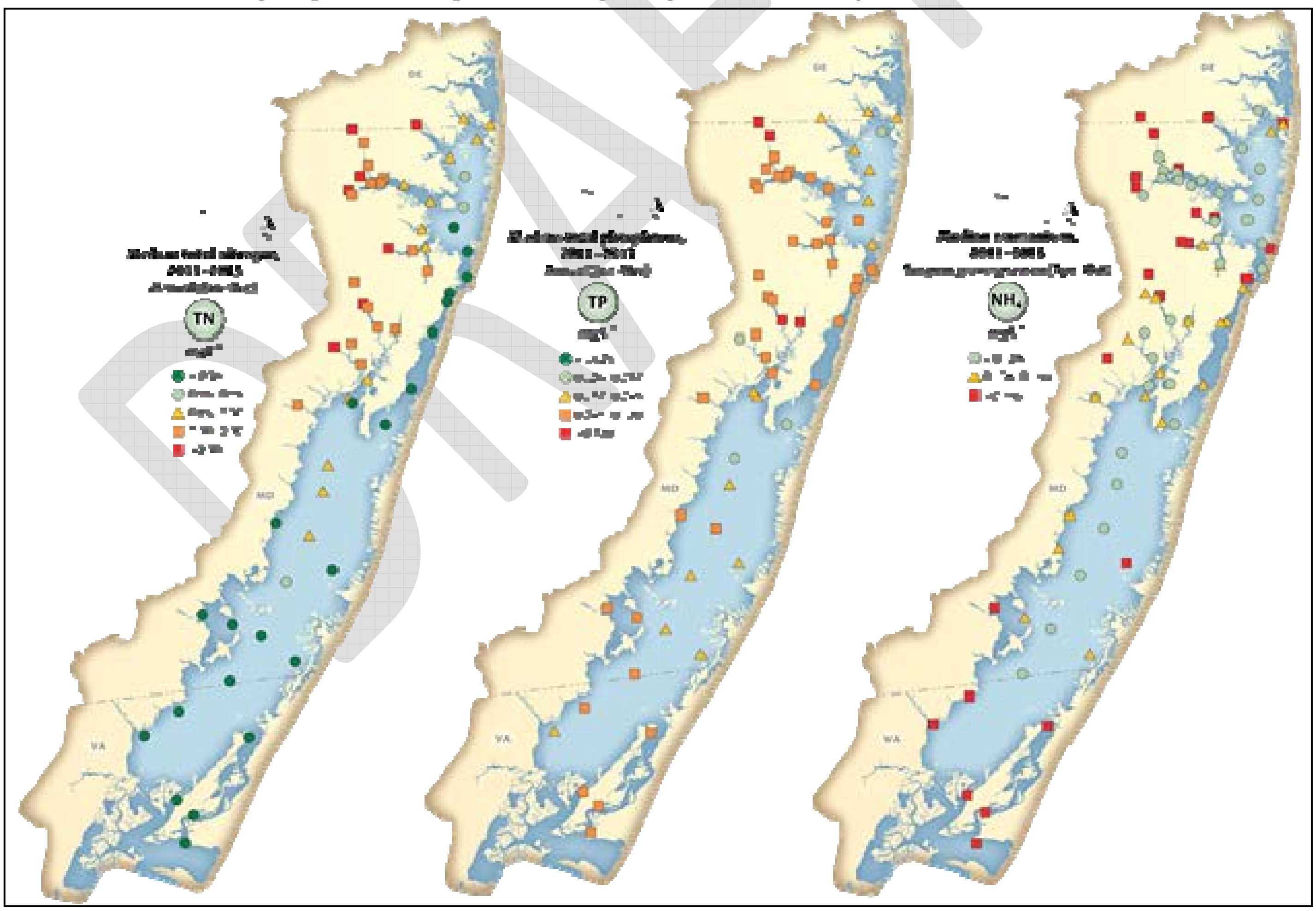


Figure 4.1.2. 2011-13 status for total nitrogen, total phosphorous and ammonium at Maryland Department of Natural Resources and Assateague Island monitoring stations.

Assawoman Bay

Eight stations were monitored in Assawoman Bay. Only three stations met either the TN or TP seagrass thresholds, and their median values were not significantly different from the upper boundary value of the criterion. Two stations met TN thresholds for SAV. One station at the headwaters of Grey's Creek (GET0005) did not meet any STAC TN objective and was classified as eutrophic (Table 4.1.2a). Only one station (XDN6454 at RT 90) passed the TP threshold for SAV (Table 4.1.2b).

Table 4.1.2a: 3-year medians of TN (mg/L) in Assawoman Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Grey's Creek	MCBP26a					1.82
	GET0005[a]	**2.29**	2.15	2.13	2.07	2.35
Fenwick Ditch	XDN7261	1.01	0.96	**0.86**	**0.81**	**0.72**
	MCBP1	**0.67**	**0.67**	0.65	0.56	0.51
Assawoman Bay	XDN7545	0.98	0.99	0.97	**0.82**	**0.75**
	XDN6454	**0.95**	**0.86**	**0.76**	**0.74**	**0.69**
	XDN5737	**0.92**	**0.93**	**0.84**	**0.74**	**0.72**
	XDN4851	0.66	0.66	0.66	0.61	0.56

Table 4.1.2b: 3-year medians of TP (mg/L) in Assawoman Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Grey's Creek	MCBP26a					0.034
	GET0005[a]	**0.058**	**0.059**	**0.051**	**0.056**	0.042
Fenwick Ditch	XDN7261	0.039	0.038	0.037	0.040	0.038
	MCBP1	0.039	0.040	0.040	0.040	0.039
Assawoman Bay	XDN7545	0.041	0.037	0.040	0.040	0.039
	XDN6454	0.036	0.035	0.039	0.039	0.037
	XDN5737	0.042	0.044	0.045	0.045	0.040
	XDN4851	0.037	0.037	0.040	0.040	0.040

Ammonium was at reaching potentially toxic levels at the two stations in Grey's Creek and at sublethal impacts at one station on Fenwick Ditch (Table 4.1.2c). Nutrient data were compatible at the co-located sites on Grey's Creek (TN fell into different categories).
(Figure 4.1.2)

Table 4.1.2c: 3-year medians of NH4 (mg/L) in Assawoman Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Grey's Creek	MCBP26a					**0.096**
	GET0005[a]	0.097	0.069	**0.107**	0.109	**0.115**
Fenwick Ditch	XDN5737	0.025	0.024	0.025	**0.016**	0.020
	MCBP1	**0.124**	**0.178**	**0.155**	**0.138**	**0.111**
Assawoman Bay	XDN6454	0.041	0.049	0.056	0.027	0.035
	XDN7261	0.066	0.086	0.064	0.038	0.038
	XDN7545	0.030	0.029	0.022	0.020	0.021
	XDN4851	0.029	0.019	0.017	**0.014**	0.016

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
[a] - stations with the same letter are co-located

St. Martin River

None of the 16 stations met TN or TP seagrass thresholds during any analytical timeframe. All stations but four were considered eutrophic for TN. The less impacted stations (XDN3724, XDN4312, M3 and M22) were located lower in the river, suggesting positive influence by water exchange with Isle of Wight Bay. Station XDN4312, in the mid St. Martin River, was on the cusp of STAC TN failure during 4 of 5 analytical timeframes (Table 4.1.3a). TP levels showed all sites were eutrophic (Table 4.1.3b)

Table 4.1.3a 3-year medians of TN (mg/L) in St. Martin River

Area	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	BNT0012	2.42	2.42	3.14	3.16	3.47
	BSH0030	2.58	2.69	2.78	2.77	2.68
	MCBP11					1.64
	XDM4486	2.07	1.97	1.92	1.77	1.84
	BSH0008	1.68	1.69	1.63	1.59	1.58
Shingle Landing Prong	MXE0011	1.50	1.50	1.43	1.39	1.32
	BIH0009	2.55	2.43	2.23	2.14	2.19
	MCBP25					2.31
	SPR0009	1.55	1.56	1.64	1.34	1.35
	SPR0002	1.52	1.43	1.43	1.29	1.30
St. Martin River	MCBP13	1.24	1.24	1.16	1.11	1.19
	XDM4797	1.25	1.20	1.14	1.08	1.15
	MCBP22	1.20	1.13	1.08	0.92	0.92
	MCBP3	0.98	0.86	0.83	0.67	0.66
	XDN4312	0.97	0.98	1.02	0.99	0.95
	XDN3724	0.78	0.78	0.85	0.80	0.76

Table 4.1.3b 3-year medians of TP (mg/L) in St. Martin River

Area	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	BNT0012	0.067	0.073	0.092	0.092	0.084
	BSH0030	0.130	0.121	0.160	0.146	0.126
	MCBP11					0.121
	XDM4486	0.151	0.129	0.148	0.135	0.119
	BSH0008	0.089	0.082	0.112	0.105	0.096
Shingle Landing Prong	MXE0011	0.100	0.101	0.123	0.120	0.095
	BIH0009	0.085	0.077	0.097	0.100	0.083
	MCBP25					0.057
	SPR0009	0.101	0.094	0.104	0.093	0.084
	SPR0002	0.081	0.089	0.094	0.083	0.068
St. Martin River	MCBP13	0.077	0.091	0.078	0.073	0.083
	XDM4797	0.074	0.078	0.070	0.063	0.066
	MCBP22	0.091	0.089	0.087	0.073	0.073
	MCBP3	0.068	0.067	0.068	0.060	0.060
	XDN4312	0.055	0.058	0.066	0.066	0.059
	XDN3724	0.045	0.046	0.051	0.059	0.055

Median NH_4 concentrations during the SAV growing season passed at nine of the sites and was above concentrations considered to be lethal to seagrasses at five sites (Table 4.1.3c) and moderate at MCBP13. One site (M11) had sub-lethal NH_4 levels that are still harmful to seagrasses. (Figure 4.1.2)

Table 4.1.3c 3-year medians of NH4 (mg/L) in St. Martin River

Area	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	BNT0012	0.130	0.131	0.159	0.270	0.206
	BSH0030	0.098	0.096	0.138	0.109	0.143
	MCBP11					0.037
	XDM4486	0.016	0.011	0.016	0.010	0.021
	BSH0008	0.013	0.014	0.011	0.015	0.017
Shingle Landing Prong	MXE0011	0.098	0.122	0.131	0.151	0.160
	BIH0009	0.218	0.223	0.221	0.218	0.229
	MCBP25					0.290
	SPR0009	0.016	0.012	0.018	0.011	0.017
	SPR0002	0.011	0.007	0.010	0.010	0.016
St. Martin River	MCBP13	0.045	0.040	0.043	0.061	0.071
	XDM4797	0.013	0.012	0.012	0.012	0.012
	MCBP22	0.028	0.015	0.015	0.015	0.016
	MCBP3	0.034	0.025	0.023	0.018	0.021
	XDN4312	0.017	0.010	0.010	0.010	0.012
	XDN3724	0.024	0.016	0.011	0.010	0.011

Isle of Wight Bay

The five stations in the open bay and one on Manklin Creek consistently met the TN seagrass threshold (6/15 sites=40%) (Table 4.1.4a). Seven stations on Manklin, Turville, and Herring creeks consistently failed the TN seagrass threshold (MKL0010, TUV0011, TUV0019, TUV0034, HEC0012, M16, M30), of which 4 were considered eutrophic (TUV0019, TUV0034, M30, HEC0012) (Table 4.1.4a). Although no stations were considered eutrophic, no station met the TP seagrass threshold (11/15= 73%) (Table 4.1.4b). Stations in the open bay generally showed better TP conditions than stations in tributaries.

Table 4.1.4a: 3-year medians of TN (mg/L) in Isle of Wight Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP16	0.99	0.95	0.86	0.87	0.78
	MKL0010	0.75	0.76	0.76	0.74	0.68
	MCBP9	0.62	0.61	0.61	0.67	0.55
Turville Creek	TUV0034	2.63	2.65	2.58	2.55	2.58
	MCBP30	1.15	1.22	1.21	1.19	1.00
	TUV0019	1.11	1.13	1.23	1.19	1.04
	TUV0011	0.75	0.75	0.77	0.77	0.73
Herring Creek	HEC0012	1.04	1.02	0.97	0.99	1.03
	MCBP6					0.69
Isle Of Wight Bay	XDN3445	0.61	0.62	0.63	0.62	0.56
	XDN2340	0.55	0.56	0.56	0.56	0.50
	MCBP34	0.54	0.56			
	MCBP5	0.32	0.32	0.32	0.32	0.31
	XDN2438	0.47	0.47	0.44	0.45	0.45
	XDN0146	0.46	0.46	0.47	0.47	0.46

Table 4.1.4b: 3-year medians of TP (mg/L) in Isle of Wight Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP16	0.095	0.074	0.066	0.064	0.070
	MKL0010	0.050	0.052	0.052	0.045	0.044
	MCBP9	0.064	0.074	0.076	0.076	0.072
Turville Creek	TUV0034	0.079	0.075	0.075	0.075	0.066
	MCBP30	0.085	0.088	0.087	0.065	0.069
	TUV0019	0.063	0.057	0.058	0.057	0.057
	TUV0011	0.050	0.046	0.047	0.046	0.047
Herring Creek	HEC0012	0.066	0.061	0.067	0.064	0.064
	MCBP6					0.064
Isle of Wight Bay	XDN3445	0.042	0.039	0.042	0.039	0.038
	XDN2340	0.039	0.041	0.046	0.047	0.047
	MCBP34	0.039	0.039			
	MCBP5	0.038	0.042	0.044	0.043	0.041
	XDN2438	0.043	0.042	0.039	0.043	0.041
	XDN0146	0.048	0.041	0.042	0.043	0.046

Table 4.1.4c 3-year medians of NH4 (mg/L) in Isle of Wight Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP16	0.049	0.046	0.040	0.046	0.047
	MKL0010	0.013	0.009	0.009	0.007	0.011
	MCBP9	0.072	0.066	0.058	0.058	0.056
Turville Creek	TUV0034	0.042	0.041	0.038	0.042	0.039
	MCBP30	0.081	0.056	0.040	0.040	0.038
	TUV0019	0.034	0.024	0.019	0.019	0.022
	TUV0011	0.019	0.013	0.013	0.008	0.009
Herring Creek	HEC0012	0.020	0.016	0.018	0.014	0.017
	MCBP6					0.020
Isle of Wight Bay	XDN3445	0.027	0.020	0.010	0.010	0.010
	XDN2340	0.025	0.015	0.012	0.008	0.009
	MCBP34	0.027	0.027			
	MCBP5	0.036	0.037	0.039	0.041	0.045
	XDN2438	0.014	0.008	0.011	0.012	0.013
	XDN0146	0.017	0.014	0.014	0.014	0.014

Ammonium levels were generally good (9/14 stations, 64%, met NH4 thresholds), and only considered potentially harmful to seagrass at one station on Manklin Creek (M9) (Table 4.1.1c). No sites were monitored by multiple programs in Isle of Wight Bay. (Figure 4.1.2)

Sinepuxent Bay

TN concentrations were well below the seagrass threshold at all seven stations during all analytical timeframes (Table 4.1.5a). One station (A16) met the TP seagrass threshold during the most recent (2011-13) timeframe. During the same timeframe, most other stations failed the TP seagrass threshold. Five out of seven stations (71%) failed TP ecosystem health threshold and are considered eutrophic. TP status appears to be worsening over time at 4 of these 6 stations (Table 4.1.5b).

Table 4.1.5a: 3-year medians of TN (mg/L) in Sinepuxent Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
West OC Harbor	ASIS1	0.35	0.35	0.35	0.33	0.30
Sinepuxent Bay	ASIS17	0.28	0.28	0.27	0.26	0.24
	ASIS18	0.31	0.30	0.27	0.28	0.26
	MCBP31	0.37	0.37	0.32	0.32	0.31
	ASIS2	0.37	0.36	0.38	0.38	0.33
	MCBP10	0.41	0.43	0.43	0.43	0.38
	ASIS16	0.47	0.47	0.38	0.37	0.35

Table 4.1.5b: 3-year medians of TP (mg/L) in Sinepuxent Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
West OC Harbor	ASIS1	0.047	0.046	0.051	**0.050**	**0.048**
Sinepuxent Bay	ASIS17	0.041	0.037	0.040	0.044	**0.050**
	ASIS18	0.038	0.036	0.036	0.042	0.046
	MCBP31	0.041	0.041	0.040	0.038	0.038
	ASIS2	0.036	0.036	0.039	0.045	0.043
	MCBP10	0.031	0.032	0.042	0.043	0.049
	ASIS16	0.039	0.041	0.040	0.039	0.035

Median NH_4 concentrations were consistently high at the two northernmost stations (A1, A17), at levels harmful to seagrasses. The southernmost station (A16) fluctuated between meeting the seagrass objective (Table 4.1.5c). (Figure 4.1.2).

Table 4.1.5c: 3-year medians of NH4 (mg/L) in Sinepuxent Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
West OC Harbor	ASIS1	**0.111**	**0.104**	**0.095**	**0.091**	**0.088**
Sinepuxent Bay	ASIS17	0.065	0.095	0.073	0.073	0.054
	ASIS18	0.053	0.047	0.036	0.042	0.048
	MCBP31	0.060	0.062	0.054	0.054	0.054
	ASIS2	0.031	0.021	0.032	0.082	0.042
	MCBP10	0.035	0.036	0.035	0.046	0.046
	ASIS16	0.027	0.045	0.019	0.034	0.025

Newport Bay

All stations except one in the lower bay (ASIS 3) consistently failed the TN seagrass threshold. Trappe, Ayers, and Marshall creeks and Newport Creek failed the TN threshold and were also classified as eutrophic (Table 4.1.6a). Only one station consistently met the STAC TP threshold, at the head of Beaverdam Creek (BMC0011). During the first and last analysis periods, this station also met the seagrass threshold. All other sites except the two open bay sites failed the STAC TP threshold and were classified as eutrophic. Three stations on Trappe Creek (AYR0017, M33, TRC0043) fell into the most impacted category (Table 4.1.6b).

Results from one station sampled by both DNR and MCBP (TRC0059/M35) were inconsistent for TN and two sites were inconsistent for NH_4 - one on Ayres Creek (AYR0017/M33) and one on Marshall Creek (MSL0011/M12) (Figure 4.1.2a and c). These comparisons suggest possible variation in sample collection times that may have captured sporadic events.

Table 4.1.6a: 3-year medians of TN (mg/L) in Newport Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Trappe Creek	KIT0015	1.64	1.63	1.42	1.25	1.29
	BOB0001	3.01	2.92	3.01	2.76	2.69
	MCBP4				2.81	2.60
	MCBP23	1.61	1.62	1.48	1.51	1.45
	TRC0059[a]	1.81	1.78	1.74	1.74	1.74
	MCBP35[a]	2.94	2.91	2.93	2.87	2.61
	TRC0043	1.85	1.76	1.74	1.70	1.68
Ayers Creek	AYR0017[b]	1.98	1.88	1.78	1.78	1.84
	MCBP33[b]	1.41	1.57	1.53	1.44	1.33
Newport Creek	BMC0011	5.78	5.55	5.55	5.50	5.91
	NPC0031	1.65	1.49	1.51	1.53	1.64
	NPC0012	1.47	1.44	1.44	1.44	1.40
Newport Bay	MCBP15	0.73	0.76	0.73	0.80	0.73
	XCM4878	0.89	0.88	0.82	0.81	0.76
	ASIS4	0.82	0.86	0.81	0.79	0.65
	ASIS3	0.63	0.64	0.60	0.60	0.46
Bassett Ck	MCBP28	3.23	2.51	2.93	2.90	2.55
Marshall Creek	MSL0011[c]	1.78	1.71	1.56	1.55	1.60
	MCBP12[c]	1.31	1.37	1.37	1.19	1.15

Table 4.1.6b: 3-year medians of TP (mg/L) in Newport Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Trappe Creek	KIT0015	0.048	0.050	0.052	0.052	0.046
	BOB0001	0.055	0.057	0.073	0.071	0.046
	MCBP4				0.092	0.073
	MCBP23	0.049	0.046	0.058	0.062	0.061
	TRC0059[a]	0.073	0.073	0.086	0.079	0.052
	MCBP35[a]	0.065	0.066	0.077	0.071	0.052
	TRC0043	0.117	0.114	0.109	0.113	0.108
Ayers Creek	AYR0017[b]	0.113	0.106	0.098	0.106	0.108
	MCBP33[b]	0.074	0.073	0.101	0.119	0.119
Newport Creek	BMC0011	0.036	0.040	0.040	0.037	0.032
	NPC0031	0.075	0.069	0.070	0.073	0.075
	NPC0012	0.068	0.060	0.060	0.061	0.061
Newport Bay	MCBP15	0.035	0.033	0.051	0.055	0.053
	XCM4878	0.050	0.044	0.043	0.041	0.040
	ASIS4	0.064	0.063	0.060	0.055	0.047
	ASIS3	0.052	0.048	0.046	0.047	0.040
Bassett Ck	MCBP28	0.030	0.034	0.054	0.054	0.055
Marshall Creek	MSL0011[c]	0.075	0.070	0.070	0.070	0.072
	MCBP12[c]	0.054	0.057	0.072	0.073	0.079

a, b, c: stations with the same letter are co-located

Newport Bay met the NH_4 seagrass threshold at seven stations (TRC0043, AYR0017, NPC0031, NPC0012, M15, XCM4878, MSL0011) but failed at 63% of sites (Table 4.1.6c). NH_4 levels were toxic to seagrasses at MCBP23.

Table 4.1.6c: 3-year medians of NH4 (mg/L) in Newport Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Trappe Creek	KIT0015	0.057	0.054	0.056	0.071	0.080
	BOB0001	0.061	0.058	0.058	0.047	0.044
	MCBP4				0.064	0.053
	MCBP23	0.130	0.106	0.109	0.114	0.142
	TRC0059[a]	0.112	0.095	0.092	0.097	0.086
	MCBP35[a]	0.076	0.076	0.074	0.069	0.056
	TRC0043	0.014	0.011	0.009	0.009	0.015
Ayers Creek	AYR0017[b]	0.015	0.009	0.009	0.011	0.020
	MCBP33[b]	0.075	0.032	0.026	0.034	0.044
Newport Creek	BMC0011	0.034	0.034	0.033	0.039	0.039
	NPC0031	0.019	0.019	0.018	0.026	0.027
	NPC0012	0.021	0.016	0.014	0.014	0.018
Newport Bay	MCBP15	0.036	0.027	0.020	0.022	0.023
	XCM4878	0.012	0.009	0.008	0.011	0.016
	ASIS4	0.052	0.059	0.043	0.056	0.040
	ASIS3	0.064	0.063	0.063	0.063	0.038
Bassett Ck	MCBP28	0.057	0.045	0.056	0.074	0.083
Marshall Creek	MSL0011[c]	0.017	0.016	0.014	0.014	0.021
	MCBP12[c]	0.077	0.041	0.028	0.033	0.053

Chincoteague Bay

Three Maryland mainstem stations (XCM1562, XCM0159, and XBM8149) and the Marshall Creek station (MSL0011) consistently did not meet TN seagrass thresholds, while the other 14 stations did meet these thresholds during the most recent two 3-year analysis periods (Table 4.1.7a). Only one station (XCM1562) met the TP seagrass threshold, and only during the most recent (2011-13) 3-year analysis period (Table 4.1.7b). (Figure 4.1.2).

Table 4.1.7a: 3-year medians of TN (mg/L) in Chincoteague Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Maryland	XCM1562	0.72	0.71	0.72	0.70	0.67
	XCM0159	0.68	0.68	0.69	0.69	0.65
	ASIS5	0.99	0.57	0.48	0.46	0.41
	XBM5932	0.69	0.68	0.67	0.63	0.60
	MCBP18	0.48	0.46	0.49	0.48	0.38
	ASIS6	0.96	0.47	0.42	0.42	0.38
	XBM8149	0.72	0.69	0.69	0.70	0.67
	ASIS7	1.02	0.52	0.50	0.47	0.44
	ASIS14	0.73	0.47	0.40	0.40	0.35
	XBM3418	0.60	0.59	0.59	0.58	0.54
	ASIS15	0.79	0.45	0.39	0.39	0.35
	M27	0.53				
	XBM1301	0.56	0.56	0.54	0.57	0.54
Virginia	ASIS9	0.58	0.37	0.35	0.33	0.24
	ASIS10	0.56	0.41	0.35	0.32	0.29
	ASIS8	0.62	0.37	0.36	0.33	0.32
	ASIS11	0.39	0.31	0.27	0.26	0.25
	ASIS12	0.39	0.31	0.27	0.27	0.24
	ASIS13	0.42	0.30	0.26	0.25	0.23

Table 4.1.7b: 3-year medians of TP (mg/L) in Chincoteague Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Maryland	XCM1562	0.049	0.047	0.048	0.043	0.035
	XCM0159	0.047	0.049	0.050	0.046	0.038
	ASIS5	0.052	0.054	0.049	0.047	0.047
	XBM5932	0.045	0.048	0.048	0.050	0.039
	MCBP18	0.051	0.043	0.051	0.048	0.044
	ASIS6	0.040	0.039	0.041	0.044	0.042
	XBM8149	0.048	0.047	0.053	0.053	0.044
	ASIS7	0.049	0.051	0.052	0.050	0.049
	ASIS14	0.039	0.040	0.043	0.045	0.043
	XBM3418	0.041	0.041	0.043	0.048	0.042
	ASIS15	0.039	0.040	0.040	0.040	0.038
	M27	0.056				
	XBM1301	0.043	0.044	0.049	0.055	0.043
Virginia	ASIS9	0.036	0.043	0.044	0.048	0.046
	ASIS10	0.039	0.041	0.046	0.046	0.040
	ASIS8	0.036	0.040	0.043	0.051	0.045
	ASIS11	0.045	0.047	0.043	0.045	0.052
	ASIS12	0.040	0.046	0.042	0.046	0.047
	ASIS13	0.043	0.045	0.043	0.043	0.043

Ammonium concentrations during the SAV growing season were very high at the eight stations (six in Virginia) and above concentrations harmful to seagrasses (toxic levels at ASIS 12 and borderline toxic at ASIS 6). An additional four stations had elevated NH_4, for a total of 12 of the 19 sites (63%) failing the seagrass threshold (Table 4.1.7c and Figure 4.1.2). All of the six stations located in Virginia had NH_4 concentrations well above the seagrass threshold during all analysis timeframes. The six open bay stations consistently met the seagrass threshold, but these stations are in deeper waters that are not considered seagrass habitat. One half of the sites located in Maryland failed the seagrass threshold.

Table 4.1.7c: 3-year medians of NH4 (mg/L) in Chincoteague Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Maryland	XCM1562	0.018	0.011	0.011	0.013	0.013
	XCM0159	0.013	0.010	0.010	0.010	0.014
	ASIS5	0.066	0.061	0.061	0.068	0.054
	XBM5932	0.009	0.007	0.008	0.008	0.012
	MCBP18	0.017	0.027	0.029	0.031	0.029
	ASIS6	0.040	0.053	0.084	0.121	0.114
	XBM8149	0.010	0.010	0.013	0.014	0.015
	ASIS7	0.037	0.062	0.087	0.106	0.062
	ASIS14	0.057	0.042	0.052	0.053	0.045
	XBM3418	0.010	0.012	0.015	0.015	0.014
	ASIS15	0.042	0.060	0.032	0.065	0.032
	XBM1301	0.017	0.016	0.017	0.016	0.024
Virginia	ASIS9	0.072	0.098	0.115	0.115	0.073
	ASIS10	0.104	0.113	0.113	0.086	0.070
	ASIS8	0.088	0.090	0.101	0.095	0.084
	ASIS11	0.068	0.083	0.092	0.092	0.084
	ASIS12	0.081	0.100	0.118	0.135	0.131
	ASIS13	0.062	0.053	0.074	0.112	0.103

Results: Trends in nutrient concentration, 1999 - 2013
Sufficient data were available to perform trend analyses on all DNR and ASIS stations (60 total), but not on any MCBP stations. There were a number of significant linear trends, particularly for total nitrogen and dissolved nutrients. Improving (decreasing) nitrogen trends were found at 25 stations (42%), and only one station showed an increasing (degrading) trend (2%). Fewer linear trends were observed for total phosphorous, with eight decreasing (13%) and four increasing (7%). However, PO_4 showed linear trends at 16 stations, with 15 (25%) improving and only one (2%) degrading. Ammonium showed 17 linear trends, with six (10%) decreasing and 11 (18%) increasing; while 16 linear trends were found for NO_{23} (13 were improving (22%) and three degrading (5%). The results of linear trend analyses are shown in Figure 4.1.3.

Significant non-linear trends for total and dissolved nutrients were also found among stations without significant linear trends. For TN, 17 stations (28%) demonstrated improvement and had significant inverted U-shaped non-linear trends. For TP, 20 stations (33%) had significant inverted U-shaped non-linear trends, while one station (2%) was degrading and showed a significant U-shaped trend. Non-linear trends for dissolved nutrients were found at 34 stations. Significant inverted U-shaped non-linear trends were found at one station for NH_4, 19 for NO_{23}, and 11 for PO_4. Significant U-shaped non-linear trends were found at one station for NH_4 and three stations for PO_4. Most critical inflection values for TN and TP occur during 2005-2007, while those for dissolved nutrients occurred during 2004-2010. The results of these analyses are shown in Figure 4.1.3

When both trend types are considered together, many stations showed improving trends, with 42 (70%) for TN, 28 (47%) for TP, seven (12%) for NH_4, 30 (50%) for NO_{23}, and 26 (43%) for PO_4. (Table 4.1.14). Descriptions of results by embayment follow (refer to Figure 4.1.1 for stations mentioned in text).

Assawoman Bay

Within this northernmost basin, all significant linear trends were improving (Table 4.1.8a). All open bay sites demonstrated improving TN, while the stream station at GET0005 had no trend. A trend in TP was found only at one open bay station (XDN7545). No significant linear trends were found for dissolved nutrients. No significant non-linear trends were found for stations that had no linear trend for total nutrients, however significant improving non-linear trends were found for NO_{23} in Fenwick Ditch (XDN7261) and three stations (XDN545, XDN5737, XDN4851) in the northern portion of the open bay (Table 4.1.8b). (Figure 4.1.3)

Table 4.1.8a Significant linear trends
Assawoman Bay

Area	Station	p value	slope	parameter
Fenwick Ditch	XDN7545	**0.0000**	**-0.0236**	TN
Assawoman Bay	XDN7261	**0.0000**	**-0.0340**	TN
	XDN6454	**0.0000**	**-0.0180**	TN
	XDN4851	**0.0004**	**-0.0114**	TN
	XDN5737	**0.0049**	**-0.0117**	TN
Assawoman Bay	XDN7545	**0.0069**	**-0.0008**	TP

Table 4.1.8b Significant non-linear trends
Assawoman Bay

Area	Station	Trend Type	Critical Date	parameter
Fenwick Ditch	XDN7545	**inverted U**	**6-Nov-05**	NO23
Assawoman Bay	XDN7261	**inverted U**	**12-Jun-07**	NO23
	XDN4851	**inverted U**	**17-Feb-07**	NO23
	XDN5737	**inverted U**	**9-May-06**	NO23
Assawoman Bay	XDN7261	**U-shape**	**16-Jul-08**	PO4

St. Martin River

The two upstream stations on Spring Branch (BIH0009, MXE0011) and the upstream stations on the main river (XDM4797, XDN4312) all had significant improving TN linear trends (Table 4.1.9a). One significant inverted non-linear trend in TN was found at the downstream station of Bishopville Prong (BSH0008), with a critical inflection date in January 2004. All other linear TN trends were not significant. No significant linear trends for TP were found. A significant degrading linear trend for NH_4 was found in Birch Branch (BIH0009). All other linear trends for dissolved nutrients were not significant (Table 4.1.9a). Among stations without significant linear trends, a significant improving non-linear trend for TN was found in Bishopville Prong (BSH0008) (Table 4.1.9b). (Figure 4.1.3)

Table 4.1.9a Significant linear trends
St. Martin River

Area	Station	p value	slope	parameter
Spring Branch	MXE0011	**0.0012**	**-0.0400**	TN
	BIH0009	**0.0100**	**-0.0455**	TN
St. Martin River	XDM4797	**0.0021**	**-0.0203**	TN
	XDN4312	**0.0052**	**-0.0121**	TN
Spring Branch	MXE0011	**0.0004**	**-0.0219**	NO23
	SPR0009	**0.0015**	**-0.0009**	NO23
Spring Branch	BIH0009	**0.0004**	**0.0060**	NH4

Table 4.1.9b Significant non-linear trends
St. Martin River

Area	Station	Trend Type	Critical Date	parameter
Bishopville Prong	BSH0008	**inverted U**	**14-Jan-04**	TN

Isle of Wight Bay

No significant linear trends were found for TN in Isle of Wight Bay. Two stations on Turville Creek (TUV0011, TUV0019) showed significant improving non-linear trends for TN (Table 4.1.10a and Figure 4.1.3).

Only one station had a significant improving trend for TP, the upstream station on Turville Creek (TUV0034). Significant inverted non-linear trends in TN were found in Turville Creek (TUV0019, TUV0034), both with the critical inflection value in December 2005. An inverted trend was also found for TP at TUV0019, with a critical inflection value in March 2006. These inverted trend reversals indicate improving conditions for nutrients that are not reflected by linear trend analysis alone, and provide encouragement although status remains poor.

Significant improving linear trends were also observed for dissolved nutrients. Both the upstream and downstream stations on Turville Creek (TUV0011, TUV0034) showed a significant improving trend in NH_4. All three stations on Turville Creek (TUV0011, TUV0019, TUV0034) also had significant improving trends for PO_4. The station on Herring Creek (HEC0012) showed significant improving trends for both NO_{23} and PO_4. A significant improving trend was also found at the station on Manklin Creek (MKL0010) (Table 4.1.10a and Figure 4.1.3).

Among stations and parameters without significant linear trends, significant non-linear trends were observed for both total and dissolved nutrients. In Turville Creek, significant improving trends were found for both TN and TP at TUV0019, and for TP alone at TUV0011. Significant trends for dissolved nutrients were found only at open bay stations, where an improving trend for NO_{23} was observed at XDN2340, and degrading trends for PO_4 were found at XDN2438 and XDN0146, the closest stations to Ocean City Inlet (Table 4.1.10b and Figure 4.1.3).

Table 4.1.10a Significant linear trends in Isle of Wight Bay

Area	Station	p value	slope	parameter
Turville Creek	TUV0034	**0.0000**	**-0.0023**	TP
Turville Creek	TUV0034	**0.0023**	**-0.0009**	NH4
	TUV0011	**0.0072**	**-0.0008**	NH4
Herring Creek	HEC0012	**0.0011**	**-0.0005**	NO23
Manklin Creek	MKL0010	**0.0085**	**-0.0001**	PO4
Turville Creek	TUV0034	**0.0000**	**-0.0011**	PO4
	TUV0019	**0.0002**	**-0.0002**	PO4
	TUV0011	**0.0019**	**-0.0001**	PO4
Herring Creek	HEC0012	**0.0002**	**-0.0002**	PO4

Table 4.1.10b Significant non-linear trends in Isle of Wight Bay

Area	Station	Trend Type	Critical Date	parameter
Turville Creek	TUV0019	**inverted U**	**5-Dec-05**	TN
	TUV0011	**inverted U**	**6-Dec-05**	TN
Turville Creek	TUV0019	**inverted U**	**25-Mar-06**	TP
Isle of Wight Bay	XDN2340	**inverted U**	**15-Sep-06**	NO23
Isle of Wight Bay	XDN0146	**U-shape**	**2-Jun-08**	PO4
	XDN2438	**U-shape**	**25-Aug-08**	PO4

Sinepuxent Bay

A significant improving TN linear trend was found at the northernmost station (ASIS 1), closest to the Ocean City Inlet. No linear trends were found for TP. All significant linear trends for dissolved nutrients were degrading, with 3 for NH_4 (ASIS 16, ASIS 18, ASIS 17) and one for NO_{23} (ASIS 17) (Table 4.1.11a and Figure 4.1.3).

All ASIS stations besides A1 showed significant improving non-linear trends for TN. Two southern stations (ASIS 2, ASIS 16) showed improving non-linear trends for TP. The southern stations (ASIS 2, ASIS16, ASIS 18) all had significant improving non-linear trends for NO_{23} and PO_4 (Table 4.1.11b and Figure 4.1.3).

Table 4.1.11a Significant linear trends in Sinepuxent Bay

Station	p value	slope	parameter
ASIS1	**0.0029**	**-0.0052**	TN
ASIS18	**0.0091**	**0.0016**	NH4
ASIS17	**0.0011**	**0.0023**	NH4
ASIS16	**0.0038**	**0.0015**	NH4

Table 4.1.11b Significant non-linear trends in Sinepuxent Bay

Station	Trend Type	Critical Date	parameter
ASIS17	**inverted U**	**28-Jul-06**	TN
ASIS18	**inverted U**	**4-Jun-06**	TN
ASIS2	**inverted U**	**2-Jan-07**	TN
ASIS16	**inverted U**	**17-Mar-06**	TN
ASIS2	**inverted U**	**11-Oct-07**	TP
ASIS16	**inverted U**	**24-Jan-07**	TP
ASIS18	**inverted U**	**28-Mar-08**	NO23
ASIS2	**inverted U**	**26-Sep-07**	NO23
ASIS16	**inverted U**	**29-Apr-08**	NO23
ASIS18	**inverted U**	**10-Feb-08**	PO4
ASIS2	**inverted U**	**31-Jan-08**	PO4
ASIS16	**inverted U**	**21-May-08**	PO4

Newport Bay

Significant improving linear trends in TN were found at two of the upstream stations feeding Newport Creek (KIT0015, BOB0001), however the station on Beaverdam Creek (BMC0011), showed a degrading linear tend in TN concentrations. Two stations on the mainstem of Trappe Creek (TRC0043, TRC0059), two stations in Newport Bay (ASIS 3, ASIS 4), and Marshall Creek (MSL0011) also showed significant improving TN linear trends. Significant improving linear trends in NH_4 and NO_{23} were also found at KIT0015 and TRC0059, and in NO_{23} at TRC0043. Encouragingly, four stations that showed improvements in nitrogen also showed significant improving linear trends in phosphorus: both TP and PO_4 concentrations at KIT0015, TRC0043, and TRC0059; and TP at ASIS 4. While BMC0011 had significant degrading linear trends for TN and NO_{23}, it had a significant improving linear trend in TP (Table 4.1.12a and Figure 4.1.3).

Three stations in the open bay (ASIS 3, ASIS 4, XCM4878) showed significant inverted non-linear trends for both TN and TP (Table 4.1.12b and Figure 4.1.3).

Table 4.1.12a Significant linear trends in Newport Bay

Area	Station	p value	slope	parameter
Trappe Creek	KIT0015	0.0000	-0.2536	TN
	BOB0001	0.0004	-0.0475	TN
	TRC0059	0.0000	-0.1405	TN
	TRC0043	0.0000	-0.0550	TN
Newport Creek	ASIS4	0.0001	-0.0166	TN
Newport Bay	ASIS3	0.0097	-0.0079	TN
Marshall Creek	MSL0011	0.0077	-0.0294	TN
Newport Creek	BMC0011	0.0000	0.0784	TN
Trappe Creek	KIT0015	0.0000	-0.0139	TP
	TRC0059	0.0000	-0.0099	TP
	TRC0043	0.0000	-0.0091	TP
Newport Creek	BMC0011	0.0005	-0.0011	TP
Newport Bay	ASIS4	0.0042	-0.0010	TP
Trappe Creek	KIT0015	0.0000	-0.0132	NH4
	TRC0059	0.0000	-0.0105	NH4
Newport Creek	BMC0011	0.0050	-0.0007	NH4
Marshall Creek	MSL0011	0.0002	-0.0030	NH4
Trappe Creek	KIT0015	0.0000	-0.1110	NO23
	BOB0001	0.0002	-0.0401	NO23
	TRC0059	0.0000	-0.0870	NO23
	TRC0043	0.0006	-0.0007	NO23
Ayers Creek	AYR0017	0.0009	-0.0008	NO23
Newport Bay	XCM4878	0.0012	-0.0003	NO23
Newport Creek	BMC0011	0.0000	0.0809	NO23
Trappe Creek	KIT0015	0.0000	-0.0056	PO4
	BOB0001	0.0027	-0.0006	PO4
	TRC0059	0.0000	-0.0045	PO4
	TRC0043	0.0000	-0.0011	PO4
Ayers Creek	AYR0017	0.0021	-0.0003	PO4
Newport Creek	BMC0011	0.0026	-0.0004	PO4
Marshall Creek	MSL0011	0.0011	-0.0003	PO4
Newport Bay	XCM4878	0.0005	-0.0001	PO4

Table 4.1.12b Significant non-linear trendsin Newport Bay

Area	Station	Trend Type	Critical Date	parameter
Newport Bay	XCM4878	inverted U	9-Feb-06	TN
Marshall Creek	MSL0011	inverted U	2-Jun-07	TP
Newport Bay	XCM4878	inverted U	27-Dec-05	TP
	ASIS3	inverted U	6-Oct-06	TP
Newport Creek	ASIS4	inverted U	4-Oct-07	NH4
	NPC0031	U-shape	2-Jan-07	NH4
Newport Creek	ASIS4	inverted U	7-Mar-07	NO23
Newport Bay	ASIS3	inverted U	19-Jun-06	NO23
Newport Creek	ASIS4	inverted U	30-Jul-07	PO4
Newport Bay	ASIS3	inverted U	19-Jun-08	PO4

Chincoteague Bay

All significant linear trends for TN in Chincoteague Bay were improving and were found mainly in the central portion of the bay and Marshall Creek (ASIS 7, ASIS 9, ASIS 14, ASIS 15, MSL0011, XCM0159, XBM3418, XBM5932, XBM8149) (Table 4.1.13a and Figure 4.1.3). In contrast, all significant TP linear trends were degrading, and were concentrated around the town of Chincoteague (ASIS11, ASIS 12, ASIS 13). Significant inverted non-linear trends for TN were found at all open bay stations, only Marshall Creek (MSL0011) did not show a significant trend. Except for the three stations concentrated around the town of Chincoteague (ASIS 11, ASIS 12, ASIS 13), which showed no non-linear trends), all of the stations in Chincoteague Bay showed significant inverted non-linear trends for TP (Table 4.1.13b and Figure 4.1.3).

Table 4.1.13a Significant linear trends Chincoteague Bay

Area	Station	p value	slope	parameter
Maryland	XCM0159	**0.0039**	**-0.0113**	TN
	XBM5932	**0.0014**	**-0.0112**	TN
	XBM8149	0.0058	**-0.0106**	TN
	ASIS7	0.0002	**-0.0097**	TN
	ASIS14	0.0000	**-0.0094**	TN
	XBM3418	0.0001	**-0.0133**	TN
	ASIS15	0.0001	**-0.0067**	TN
Virginia	ASIS9	0.0036	**-0.0062**	TN
Virginia	ASIS11	0.0001	**0.0008**	TP
	ASIS12	0.0000	**0.0009**	TP
	ASIS13	0.0008	**0.0006**	TP
Maryland	ASIS6	**0.0089**	**0.0017**	NH4
	ASIS7	**0.0034**	**0.0015**	NH4
	ASIS9	**0.0013**	**0.0025**	NH4
Virginia	ASIS8	**0.0000**	**0.0029**	NH4
	ASIS10	**0.0085**	**0.0021**	NH4
	ASIS12	**0.0023**	**0.0030**	NH4
	ASIS13	**0.0025**	**0.0022**	NH4
Maryland	XCM0159	**0.0002**	**-0.0003**	NO23
	XBM5932	**0.0012**	**-0.0003**	NO23
	XBM8149	**0.0029**	**-0.0003**	NO23
Maryland	XCM0159	**0.0001**	**-0.0001**	PO4
	XBM5932	**0.0018**	**-0.0002**	PO4

Table 4.1.13b Significant non-linear trends Chincoteague Bay

Area	Station	Trend Type	Critical Date	parameter
Maryland	XCM1562	**inverted U**	**7-Nov-06**	TN
	ASIS5	**inverted U**	**30Oct2005**	TN
	ASIS6	**inverted U**	**11Apr2005**	TN
	XBM1301	**inverted U**	**12-Sep-06**	TN
Virginia	ASIS8	**inverted U**	**16Dec2006**	TN
	ASIS10	**inverted U**	**24Jan2006**	TN
	ASIS11	**inverted U**	**7-Feb-07**	TN
	ASIS12	**inverted U**	**27-Aug-06**	TN
	ASIS13	**inverted U**	**22-Jul-06**	TN
Maryland	XCM1562	**inverted U**	**24-Aug-06**	TP
	XCM0159	**inverted U**	**22-May-07**	TP
	ASIS5	**inverted U**	**10-May-07**	TP
	XBM5932	**inverted U**	**11-Mar-07**	TP
	ASIS6	**inverted U**	**12-Jan-07**	TP
	XBM8149	**inverted U**	**25-Jun-07**	TP
	ASIS7	**inverted U**	**23-Dec-05**	TP
	ASIS14	**inverted U**	**5-Nov-05**	TP
	XBM3418	**inverted U**	**18-Sep-06**	TP
	ASIS15	**inverted U**	**12-Jun-07**	TP
	XBM1301	**inverted U**	**7-Jan-07**	TP
Virginia	ASIS9	**inverted U**	**3-Nov-06**	TP
	ASIS8	**inverted U**	**28-Jan-07**	TP
	ASIS10	**inverted U**	**14-Nov-06**	TP
Maryland	XCM1562	**inverted U**	**1-May-06**	NO23
	ASIS5	**inverted U**	**29-Jan-06**	NO23
	ASIS6	**inverted U**	**16-Nov-06**	NO23
	ASIS7	**inverted U**	**11-Aug-07**	NO23
	ASIS14	**inverted U**	**3-Oct-06**	NO23
	ASIS15	**inverted U**	**10-Jan-07**	NO23
Virginia	ASIS8	**inverted U**	**6-Feb-08**	NO23
	ASIS13	**inverted U**	**16-Dec-06**	NO23
Maryland	XCM1562	**inverted U**	**12-Jul-05**	PO4
	ASIS5	**inverted U**	**16-Feb-08**	PO4
	ASIS7	**inverted U**	**23-Sep-07**	PO4
	ASIS14	**inverted U**	**19-Dec-07**	PO4
Virginia	ASIS9	**inverted U**	**8-Nov-07**	PO4
	ASIS10	**inverted U**	**13-Jan-08**	PO4

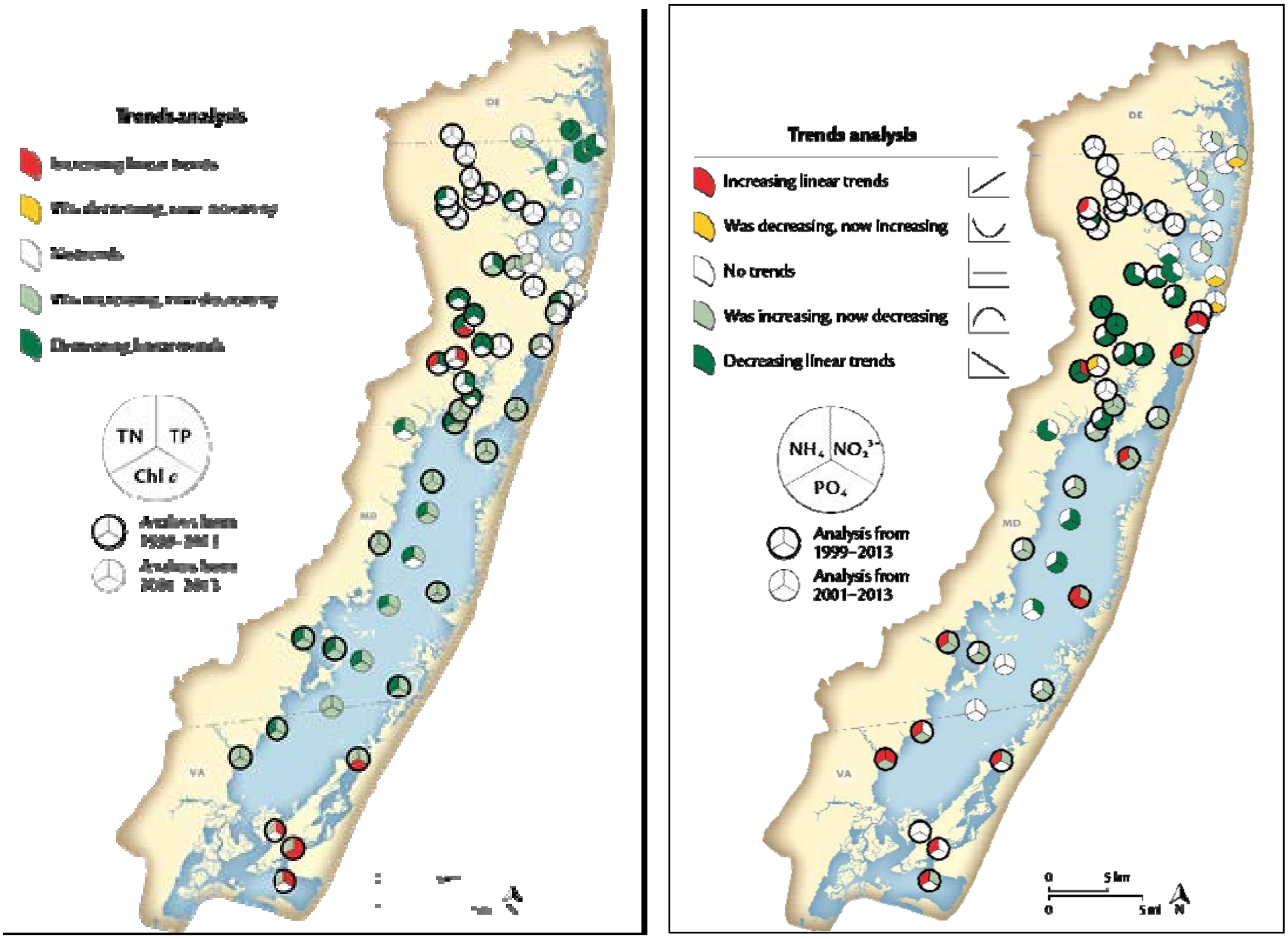


Figure 4.1.3. Nutrient trends at fixed DNR and ASIS stations. Trends were based on between 13 and 15 years of data, depending on the station. Significance in linear trends was calculated using the seasonal Kendall's tau statistic, and directionality (improving or degrading) condition for significant trends was determined by linear regression (p = 0.01 level).

Summary

The entire Coastal Bays watershed continues to be stressed by nutrients. The St. Martin River, Newport Bay, tributaries of Isle of Wight Bay, northern Chincoteague Bay, and most of Assawoman Bay remain enriched with nitrogen. In those areas that meet the seagrass threshold for TN, many stations fail the NH_4 threshold, including Sinepuxent Bay and southern Chincoteague Bay. Phosphorous enrichment is nearly ubiquitous, with only four scattered stations meeting the seagrass threshold during the most recent (2011-13) analysis period. TN and TP are better than dissolved inorganic nutrients as indicators of relative nutrient availability in systems known to have high organic inputs (Glibert et al. 2001). Elevated nutrient levels may be impacting seagrass distribution (see Chapter 5.1).

Although areas of the Coastal Bays continue to fail seagrass thresholds for nitrogen, improving total nitrogen trends were found in Assawoman Bay and at many sites in Newport Bay and Chincoteague Bay.

While the status of phosphorous remains poor throughout the bays, trends analyses indicate that concentrations are declining in recent years in the Maryland and northern Virginia portion of Chincoteague Bay but not in other areas. Legacy groundwater is increasingly understood as a source of phosphorous to the Coastal Bays, which may explain persistent failure of the seagrass threshold. It may take decades for high concentrations to decrease sufficiently to meet the threshold, even in the face of best management practices (BMPs) that improve surface water runoff quality. These BMPs should not be abandoned or scaled back because they mitigate further additions of phosphorus to groundwater and surface water. It is important that declines in phosphorous concentrations continue. In contrast, the area near Chincoteague, Virginia exhibits increasing trends, likely linked to outdated sewage treatment and management practices.

Ammonium concentrations exceeded seagrass thresholds between 32-35% of sites and were potentially lethal at some sites. Ammonium concentrations were highest in the Virginia portion of Chincoteague Bay and in tributaries watershed-wide.

Overall, one site in Assawoman Bay and three in Newport Bay overlapped between DNR and MCBP volunteer monitoring program. Results from co-located sites varied. Differences in the frequency of sample collection (monthly vs twice a month) may be a result of volunteers better capturing sporadic events. These comparisons suggest not eliminating any of the volunteer sites.

Combined linear and non-linear trends analysis detected 152 unique significant trends among all parameters and stations (50%). Out of 60 stations there were 42 significant improving trends for TN, 27 for TP, 7 for NH_4, 30 for NO_{23}, and 26 for PO_4 (Figure 4.1.3). There was one significantly degrading trend for TN, 3 for TP, 12 for NH_4, one for NO_{23}, and three for PO_4 (Table 4.1.14) Improving trends in dissolved nutrients may be one driver for improving trends in total nutrients, where both trends coincide. Declining trends in dissolved nutrients may be early warning of undetected problems, where they coincide with improving trends in total nutrients. Most trends were improving; only 20 significant degrading trends were found (7%)

The improving trends in the St. Martin River are encouraging, because it is one of the most impacted segments within the Coastal Bays watershed. If the degrading trend in NH_4 at Birch Branch continues, it may have a negative impact on the improving trend in TN. Phosphorus and ammonium levels indicate large scale nutrient issues that need to be addressed. Ammonium toxicity effects on Z. marina are expected to be strongest in the fall when irradiance decreases, temperature is still high, and ambient ammonium concentrations rise. Therefore, a different temporal average for ammonium should be investigated to determine potential toxicity impacts.

Table 14.1.14 Summary of significant nutrient trends in each subwatershed (linear and non-linear). Green columns indicate the number of improving trends while the pine columns are degrading trends.

TN

Area	Linear		Non-Linear	
Assawoman Bay	5	0	0	0
St. Martin River	4	0	1	0
Isle of Wight Bay	0	0	2	0
Sinepuxent Bay	1	0	4	0
Newport Bay	7	1	1	0
Chincoteague Bay	8	0	9	0

TP

Area	Linear		Non-Linear	
Assawoman Bay	1	0	0	0
St. Martin River	0	0	0	0
Isle of Wight Bay	1	0	1	0
Sinepuxent Bay	0	0	2	0
Newport Bay	5	0	3	0
Chincoteague Bay	0	3	14	0

NH4

Area	Linear		Non-Linear	
Assawoman Bay	0	0	0	0
St. Martin River	0	1	0	0
Isle of Wight Bay	2	0	0	0
Sinepuxent Bay	0	3	0	0
Newport Bay	4	0	1	1
Chincoteague Bay	0	7	0	0

NO23

Area	Linear		Non-Linear	
Assawoman Bay	0	0	4	0
St. Martin River	2	0	0	0
Isle of Wight Bay	1	0	1	0
Sinepuxent Bay	0	0	3	0
Newport Bay	6	1	2	0
Chincoteague Bay	3	0	8	0

PO4

Area	Linear		Non-Linear	
Assawoman Bay	0	0	0	1
St. Martin River	0	0	0	0
Isle of Wight Bay	5	0	0	2
Sinepuxent Bay	0	0	3	0
Newport Bay	8	0	2	0
Chincoteague Bay	2	0	6	0

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Chapter 4.2

Status and trends of phytoplankton abundance in the Maryland Coastal Bays

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Abstract
High concentrations of phytoplankton can lead to a reduction in water clarity and dissolved oxygen, creating unsuitable conditions for living resources (fish, shellfish, and seagrasses). Algae abundance was monitored in the Coastal Bays by measuring water column chlorophyll concentrations using fixed station and continuous monitor data. Phytoplankton abundance in Assawoman, Isle of Wight, Sinepuxent, and Chincoteague bays was generally low enough to allow for seagrass growth during 2007-2013. The St. Martin River and tributaries of Newport Bay demonstrated high chlorophyll levels (20.5% of sites) and failed the thresholds established for seagrass growth and dissolved oxygen. Many tributaries with failing nutrient thresholds also had elevated water column chlorophyll levels, while the open bays generally had lower chlorophyll levels more suitable for seagrasses. Continuous monitoring estimates of chlorophyll suggest possible improvement over time. Chlorophyll attainment related to the Total Maximum Daily Load analyses showed improvement in Sinepuxent and Isle of Wight bays. Many areas show improving trends in chlorophyll *a*, scientists anticipate that seagrasses will respond positively in time.

Introduction

Phytoplankton are an important food source to many living resources (shellfish and fish) in the Coastal Bays. However, large algae blooms in the water column can have detrimental effects on water quality. Blooms may lead to oxygen depletion that stresses or kills fish and shellfish. High levels of water column algae can also limit the amount of light available to seagrasses.

The concentration of chlorophyll, the green pigment in algae, is often used to represent the amount of algae in the water column. These amounts are affected by a number of factors, including temperature, light, nutrient levels, and grazing by zooplankton, planktivorous fish, and shellfish. Persistent efforts to reduce the amount of nutrients entering the watershed are expected to reduce chlorophyll levels and thus improve water clarity and oxygen levels, particularly in tributaries that have continued to fail management objectives.

Data Sets

A wealth of information is available on phytoplankton abundance through monthly monitoring of water column chlorophyll *a* at numerous **fixed stations** throughout the Coastal Bays. The National Park Service at Assateague Island National Seashore (ASIS) has conducted monthly chlorophyll *a* monitoring at 18 fixed stations in the southern bays since 1987. The Maryland

Department of Natural Resources (DNR) has monitored chlorophyll *a* monthly at 28 fixed sites in the St. Martin River and Newport Bay since 1998 and at 17 fixed sites in Assawoman, Isle of Wight, and Chincoteague Bays since 2001. The Maryland Coastal Bays Program (MCBP) implemented a volunteer water quality monitoring program in 1997 and has monitored chlorophyll at 26 fixed stations since 2007. Samples were sent to laboratories at the Maryland Department of Health and Mental Hygiene (DNR 2007-08) or the University of Maryland (DNR 2009-13, ASIS and MCBP) for extractive spectrophotometric (DNR and MCBP) or High-performance liquid chromatography (ASIS) analysis of chlorophyll *a* concentration. All three programs collect data in accordance with EPA-approved quality assurance project plans. An additional five sites were sampled during August 2010, as part of EPA's National Coastal Condition Assessment and associated supplementary sampling for benthic conditions (Fig 4.3.1).

While monthly sample collection provides important information on spatial patterns of phytoplankton variation, it misses events occurring on smaller time scales (days/weeks) or at times of the day or year when it is impractical to deploy field crews. Moreover, monthly sampling efforts are snapshot events, and cannot provide data on the duration of poor water quality episodes. To assess chlorophyll concentrations at these finer time scales, **continuous monitors** have been deployed in the Coastal Bays – five by DNR and two by ASIS (Figure 4.2.1). These monitors measure a suite of water quality parameters every 15 minutes. At four sites data are telemetered to a website for near real-time viewing (Maryland Department of Natural Resources 2004). Continuous monitors estimate total chlorophyll *in situ* u sing a built-in fluorometer. Although this method cannot distinguish between the various forms of chlorophyll, the dominant form found in surface water samples is typically chlorophyll *a*. Continuous monitoring data allows scientists to learn more about the ecosystem by tracking daily fluctuations in chlorophyll and linking them to real-time events, such as fish kills or harmful algae blooms.

Management Objective: Maintain suitable fisheries habitat.

> **Algae Indicator 1:** 50 μg/L for dissolved oxygen effects
> **Algae Indicator 2:** 15 μg/L for effects on seagrasses

Analyses

Status:

1) Fixed stations: For each fixed monitoring station (Figure 4.2.1), a median chlorophyll *a* concentration was determined for the seagrass growing season (March - November) for rolling three-year periods from 2007-2013. Threshold values developed by the Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC), based on living resources indicators (see Management Objective above) (Table 4.2.1), were used as the basis for a 5-category attainment series. Each median value was compared to its category cut-off values using the non-parametric Wilcoxon sign-rank test. Those medians that were significantly different at $p=0.01$ from both category cutoffs were considered statistically significant overall.

2) Continuous monitoring: Frequency of threshold failure was determined using temporally intensive continuous monitoring data from 2007 and 2013. DNR continuous monitoring data were compared to monthly and biweekly laboratory data from grab samples collected simultaneously with sonde changeover, using a regression that includes a temperature component. (Figures 4.2.2 through 4.2.8). The calibration equation is determined by calculating a log-ratio ($\log_{grab} - \log_{sonde}$) for each event, regressing it over concomitant temperature to determine a predicted log-ratio, and multiplying the backtransformed predicted log-ratio by the sonde chlorophyll value to predict the grab chlorophyll value.

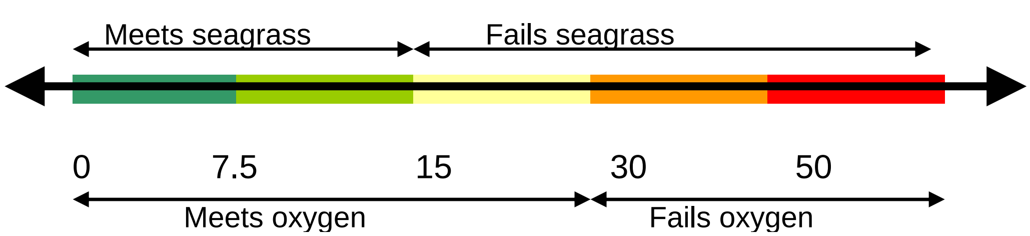
3) National Coastal Condition Assessment, NCCA, 2010: Samples were collected at five sites during August 2010 as part of an US EPA program that assess our nation's waters. One visit was made to four stations and the fifth site was visited twice, providing a snapshot of water quality conditions. Chlorophyll *a* values were placed into STAC attainment categories (Table 4.2.1).

4) Total Maximum Daily Load (TMDL) comparisons: Chlorophyll criteria for TMDL analyses use a different metric for chlorophyll than those reported above (Maryland Department of the Environment, 2014). The Maryland Department of the Environment (MDE) calculates a percent of time chlorophyll levels exceed a threshold (either 15ug/L for seagrasses and within 250 foot buffer from submerged aquatic vegetation or 50 µg/L threshold) to determine if the TMDL is met. Results are presented for comparison to STAC status analyses. Chlorophyll endpoints for the TMDL analyses have been approved by the EPA.

Table 4.2.1 Attainment category values for chlorophyll *a* in the Maryland Coastal Bays. Upper cutoff values are shown; lower cutoff values are the values from the previous category, forming category bounds for hypothesis testing. Bolded criteria and values are living resources and dissolved oxygen indicators developed by scientific and technical advisory committee.

Threshold criteria	Chlorophyll *a* cutoff values for category
Better than SAV (seagrass) objective	<7.5 µg/L
Meets SAV (seagrass) objective	**<15 µg/L**
Does not meet SAV (seagrass) objective	<30 µg/L
Dissolved oxygen concentration threatened	<50 µg/L
Threatened - does not meet any objectives	**>50 µg/L**

Chlorophyll *a* (µg/L) Threshold categories



<u>Trends:</u>
Trend analyses were used to compare the effect of time on chlorophyll *a* concentrations at fixed stations. These analyses detect changes over time that may be related to management actions. Linear and non-linear analyses were performed on all stations that have been sampled continuously since 1999 (2001 for a subset of DNR stations, and 2000 for a subset of MCBP stations), in order to make comparisons among all programs using comparable data. At least 10 continuous years of data are required for trend analyses. The Seasonal Kendall test was used to identify linear trends, and Sen's slope estimator was used to estimate the magnitude of change over time when a significant trend was present (Ebersole et al. 2002, Hirsch et al. 1982; Van Belle and Hughes 1984). At sites when no linear trend was detected, non-linear trends were evaluated to identify whether reversals in trend direction had occurred, and their corresponding inflection points, during the analysis period. For all trend tests, a significance level of $p<0.01$ was used to achieve the highest possible power.

Results: Status of Algae Abundance
The status of chlorophyll concentrations in each Coastal Bays segment is discussed below. Please refer to Figure 4.2.1 for place names and station locations. (Table 4.2.2). Comparison of monthly values to predicted values for continuous data shows relatively poor relationships during the summer months (Figure 4.2.2 through 4.2.13). This is most likely because monthly sampling is concurrent with sonde exchange, occurring when the fluorescence probe is most likely to be fouled. Chlorophyll status for the most recent 3-year analysis period (2011-13) is mapped in Figure 4.2.2.

Figure 4.2.1 Water quality monitoring station locations.

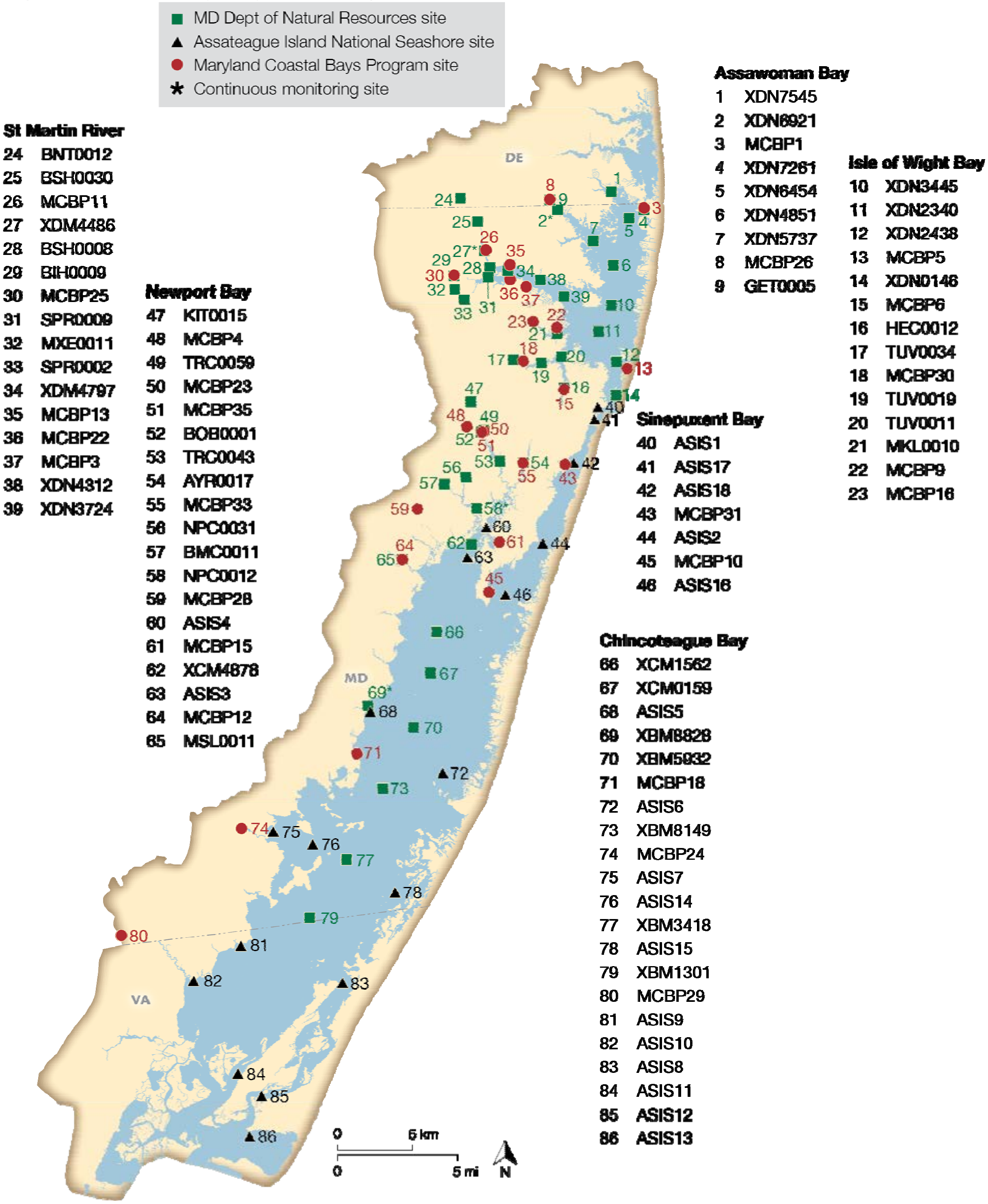
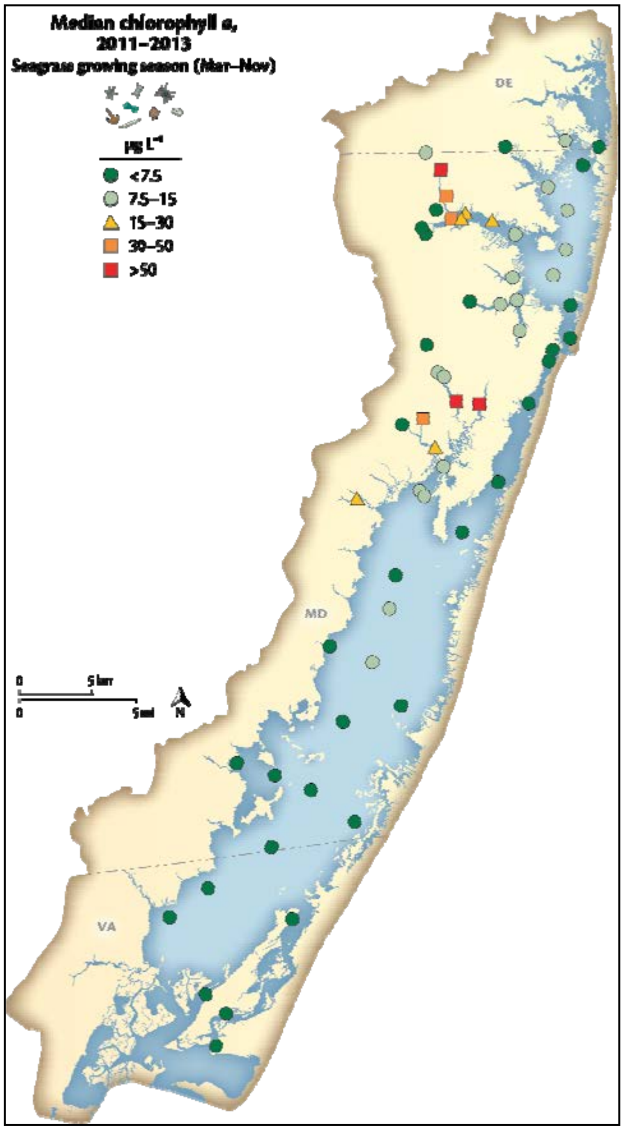


Figure 4.2.2 a) Median chlorophyll *a* concentrations (µg/L) during the seagrass growing season (March – November) at fixed stations during 2001-13. Colors indicate thresholds from Table 4.2.1. **b)** Map of 2010 National Coastal Condition Assessment chlorophyll a.

a.



b.

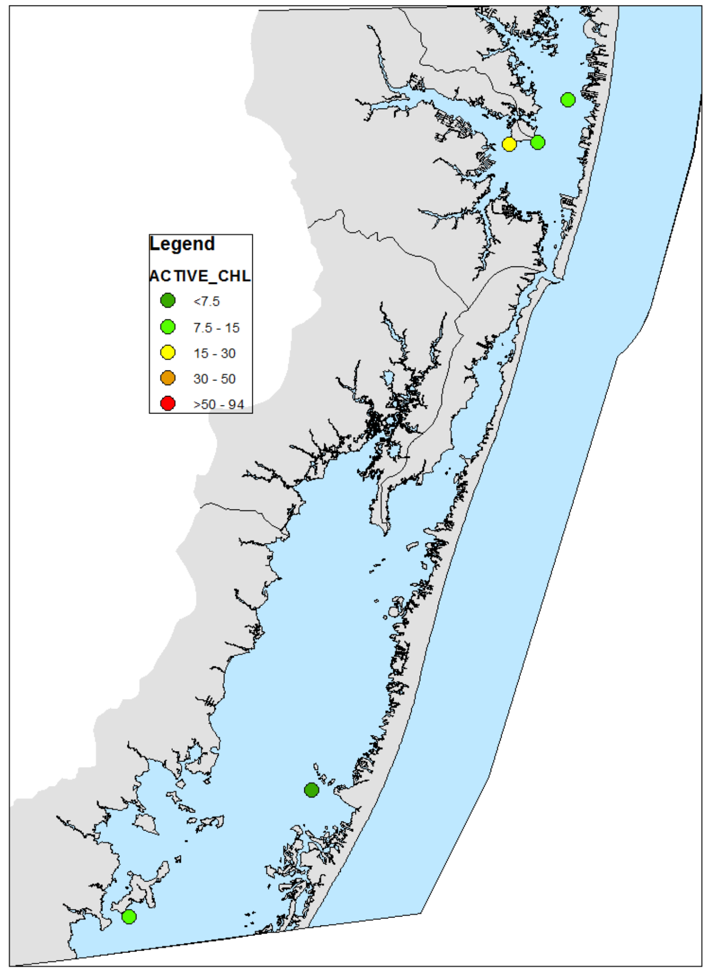
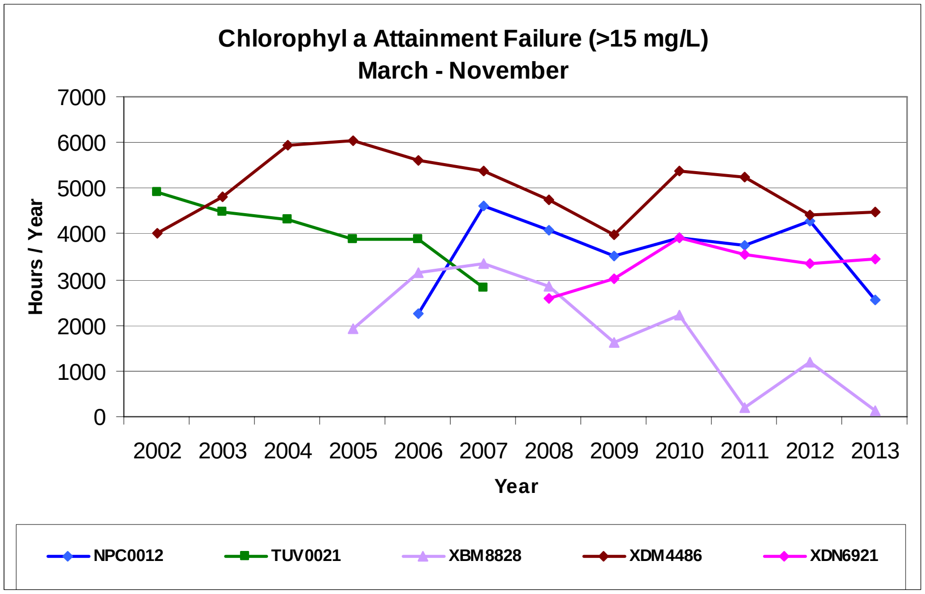


Figure 4.2.3 Total hours per year that chlorophyll *a* exceeded the 15µg/L threshold during the seagrass growing season (March – November, ~6480 max hours) at DNR continuous monitoring stations. Site locations are as follows: NPC0012 – Newport Creek TUV0021 – Turville Creek, XBM8828 – Public Landing, XDM4486 – Bishopville Prong and XDN6921 - Greys Creek.



Assawoman Bay

Fixed Station Status: All fixed stations met or exceeded seagrass thresholds during all five status timeframes (Table 4.2.2). However, at four sites (XDN4851, XDN5737, XDN7261, XDN7545), the median chlorophyll values were highest during the most recent analysis period, 2011-13.

Table 4.2.2 Rolling three year medians of chlorophyll *a* (µg/L) for stations in the Assawoman Bay watershed during seagrass growing season (March – November).

3-year medians of chlorophyll *a* (µg/L) in Assawoman Bay						
	Station	07-09	08-10	09-11	10-12	11-13
Greys Creek	MCBP 26[a]					6.3
	GET0005[a]	9.6	8.0	6.4	6.4	5.6
Fenwick Ditch	XDN7261	5.4	6.2	4.3	5.3	6.9
	MCBP 1	4.9	5.0	4.9	5.0	5.0
Roys Creek	XDN7545	8.0	9.6	6.6	9.8	11.2
Assawoman Bay	XDN6454	6.8	7.0	5.4	5.8	6.4
	XDN5737	9.7	9.0	8.1	9.9	11.7
	XDN4851	5.3	5.1	5.6	8.5	8.7

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis blank cells have no data for that timeframe
[a] stations are co-located

NCCA status: One station was sampled for NCCA during August 2010, and chlorophyll *a* met the seagrass objective (15 µg/L) at 8.61 µg/L.

Continuous monitoring Status: Despite all of the fixed stations in Assawoman Bay passing the seagrass threshold (15 µg/L), the Greys Creek continuous monitor showed that total chlorophyll measurements were seldom below the seagrass objective (7.5 µg/L) over the course of six years, with failure occurring between 88 and 98% of the time. This site also fared poorly in meeting the seagrass objective (15 µg/L), with failure occurring between 70 and 81% of the time. These data show that this area is poor seagrass habitat, however, this site rarely failed the DO threshold (>50 µg/L). There is no clear pattern of improvement or decline in performance over the 6-year monitoring period (Figure 4.2.3).

Table 4.2.3 Annual percent failure of chlorophyll criteria in Greys Creek (2007-2013).

Site	Threshold	2007	2008	2009	2010	2011	2012	2013
Greys Creek XDN6921	**CHLt > 50**	not sampled	**10.2%**	**20.6%**	**19.1%**	**9.4%**	**4.8%**	**10.5%**
	CHLt > 30		25.3%	39.8%	42.0%	31.8%	24.1%	40.5%
	CHLt > 15		**70.1%**	**70.3%**	**80.7%**	**71.7%**	**78.6%**	**75.4%**
	CHLt > 7.5		92.6%	87.7%	97.9%	91.3%	92.3%	97.0%

During the seagrass growing season, extracted values for chlorophyll *a* at Greys Creek consistently exceeded measured fluorescent and predicted values, suggesting that percent failure for chlorophyll criteria may actually have been higher during most years.

Figure 4.2.3 Comparison of extracted chlorophyll *a* vs fluorescence and predicted temperature-corrected fluorescence chlorophyll values in Greys Creek.

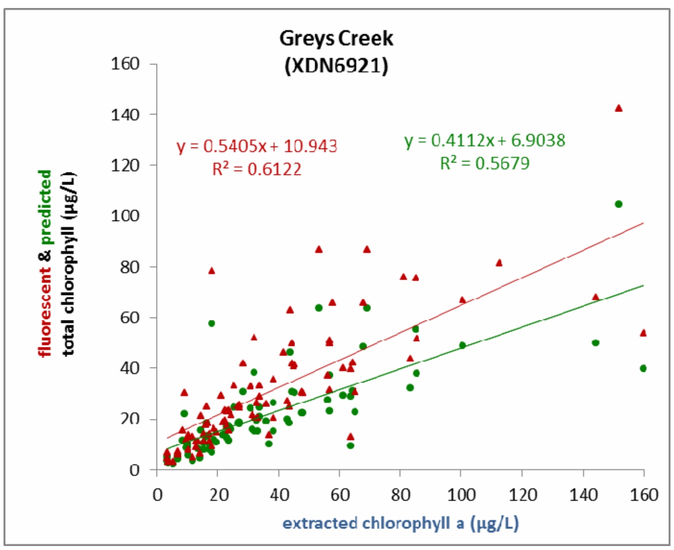
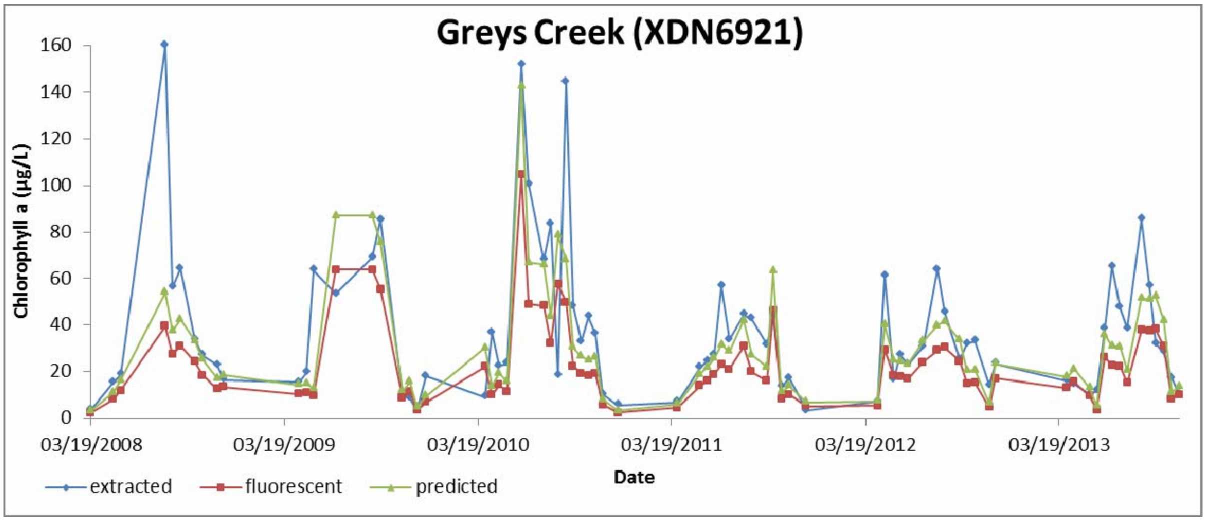


Figure 4.2.4 Comparison of chlorophyll *a* values measured by fluorescence probe, extracted and temperature corrected predicted values in Greys Creek.



<u>TMDL Status</u>: Achievement of the TMDL endpoints was achieved at all three long term monitoring sites in Assawoman Bay (Table 4.2.16). No site had values above 50 µg/L chlorophyll *a* although the continuous monitor at Greys Creek showed exceedance of 50 µg/L chl in 2008 and 2010 (Table 4.2.16).

St. Martin River

<u>Fixed Station Status</u>: Four sites consistently met or exceeded the seagrass threshold of 15 µg/L: Birch Branch and Middle Branch, a station located mid-river (MCBP 3), and the farthest downstream station (XDN3724). Spring Branch continues to struggle, with medians well above the 15 µg/L threshold. With the exception of XDN4312 in mid-river, there is little evidence of change across the rolling 3-year medians at these sites. Although during the first two 3-year analysis intervals beginning in 2007, the upstream Bishopville Prong site (XDM4486) did pass the 50 µg/L threshold, it has since failed to pass and was therefore considered eutrophic. As with Greys Creek in Assawoman Bay, the chlorophyll thresholds were not applicable to non-tidal sites on Bishopville and Shingle Landing prongs (Figure 4.2.2).

Table 4.2.4 Rolling three year medians of chlorophyll *a* (µg/L) for stations in the St. Martin River watershed during seagrass growing season (March – November).

3-year medians of chlorophyll *a* (µg/L) in St. Martin River						
	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	MCBP 11	13.7			25.9	25.5
	XDM4486*	47.0	35.9	51.3	58.7	58.7
	BSH0008	30.9	29.0	36.6	42.0	42.0
Shingle Landing Prong	MXE0011	**4.4**	**2.7**	**4.0**	**3.7**	**3.2**
	BIH0009	**3.6**	**2.8**	**2.7**	**3.2**	**2.7**
	MCBP 25					**1.8**
	SPR0009	31.3	31.0	31.3	35.8	35.6
	SPR0002	31.0	26.2	31.0	33.6	28.8
St Martin River	MCBP 13	19.7	19.7	17.9	16.6	17.3
	XDM4797	**23.4**	**24.6**	22.3	**24.6**	21.7
	MCBP 22	18.9	18.9	16.6	16.6	16.8
	MCBP 3	14.3	13.7	14.2	13.2	13.7
	XDN4312	14.6	**23.4**	16.2	16.8	15.8
	XDN3724	8.5	13.5	**9.9**	**9.4**	**11.4**

*also a continuous monitoring station

NCCA status: One station was sampled twice during 2010. During August chlorophyll *a* passed the seagrass objective (7.5 µg/L) at 4.57 µg/L; however, during September the value failed the seagrass objective (15 µg/L) at 24.73 µg/L. These results demonstrate the high variability of chlorophyll *a* in highly eutrophic areas, and thus the difficulty in using snapshots and measures of central tendency (mean=14.7 µg/L meets seagrass objective) to characterize status.

Continuous monitoring Status: During March through November of all seven years, the Bishopville Prong continuous monitor showed that total chlorophyll concentrations failed the seagrass threshold (15 µg/L) over 80% of the time. Performance was somewhat better at higher concentration thresholds (30 and 50 µg/L thresholds respectively), with failure between 55 and 77%, and 20 and 43% of the time (Table 4.2.5). This is a marked improvement from 2002 when failures occurred 84 and 94 percent of the time, but similar to 2003 (46 and 68 percent of the time).

Table 4.2.5 Annual percent failure rate of chlorophyll criteria from 2007-2013.

Site	Threshold	2007	2008	2009	2010	2011	2012	2013
Bishopville Prong XDM4486	**CHL > 50**	**32.5%**	**20.4%**	**33.2%**	**31.4%**	**26.2%**	**28.0%**	**43.5%**
	CHL > 30	76.0%	54.9%	58.6%	69.7%	69.4%	69.6%	77.3%
	CHL > 15	**95.2%**	**93.1%**	**82.1%**	**97.0%**	**92.7%**	**91.4%**	**94.7%**
	CHL > 7.5	99.1%	99.7%	93.2%	100.0%	99.8%	95.5%	99.8%

During the seagrass growing season, extracted values for chlorophyll *a* at Bishopville Prong frequently exceeded measured fluorescent and predicted values during 2009-2013, suggesting that percent failure for the higher concentration chlorophyll criteria may actually have been greater during those years.

Figure 4.2.5 Comparison of extracted chlorophyll *a* vs fluorescence and predicted temperature-corrected fluorescence chlorophyll values in Bishopville Prong (2007-2013).

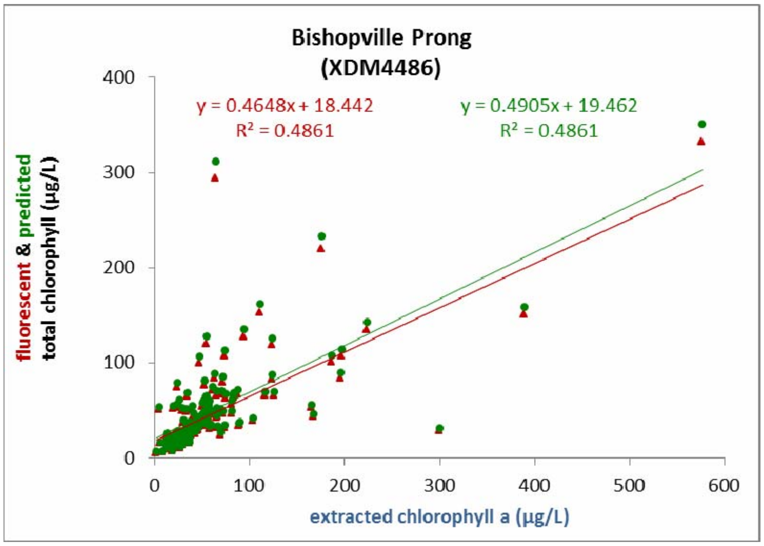
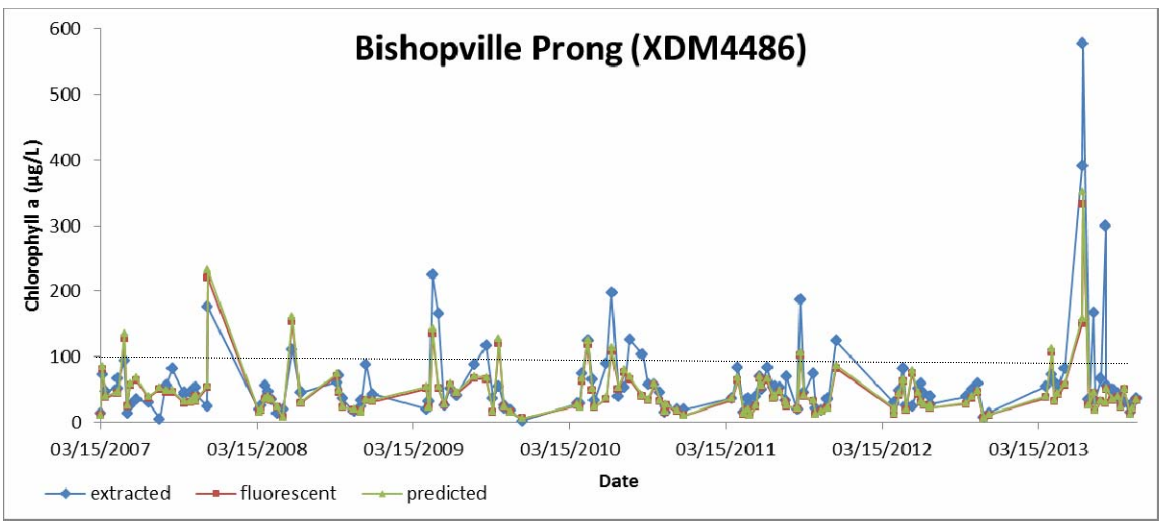


Figure 4.2.6 Comparison of chlorophyll *a* values measured by fluorescence probe, extracted and temperature corrected predicted values in Bishopville Prong.



<u>TMDL Status</u>: Achievement of the total maximum daily load endpoints in the St Martin River ranged from 0% (downstream) to 70.6% (upper river) of chlorophyll levels above 50 µg/L (Table 4.2.16). Only three stations had values above 100 µg/L (BSH008-8.3%; SPR0009 – 5.6% and SPR0002 – 2.8%). Additionally, the continuous monitor at Bishopville Prong showed nearly annual exceedances (Table 4.2.16).

Isle of Wight Bay

Fixed Station Status: All fixed stations except MCBP 30 met or exceeded seagrass thresholds during all years (Figure 4.2.1). Sites nearest the inlet had the lowest chlorophyll concentrations (likely influenced by clear water coming in from the ocean). Sites in the tributaries typically had the highest concentrations.

Table 4.2.6 Rolling three year medians of chlorophyll *a* (µg/L) at stations in the Isle of Wight Bay watershed during seagrass growing season (March – November).

3-year medians of chlorophyll *a* (µg/L) in Isle of Wight Bay						
	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP 16	4.7	8.2	10.7	11.6	8.9
	MKL0010[a]	12.5	12.5	12.8	13.9	12.1
	MCBP 9[a]	6.3	7.2	7.4	7.1	5.7
Turville Creek	TUV0034	**1.5**	**1.8**	2.1	**1.8**	**1.2**
	MCBP 30	15.8	14.2	17.5	17.2	17.2
	TUV0019	13.0	12.7	13.0	13.8	12.5
	TUV0011	9.8	10.0	10.3	12.7	**11.2**
Herring Creek	HEC0012[b]	14.0	15.0	15.0	10.5	10.7
	MCBP 6[b]				9.5	9.3
Isle of Wight Bay	XDN3445	5.3	5.4	5.6	9.6	10.0
	XDN2340	**5.3**	**5.5**	6.7	9.1	8.6
	MCBP 5	**1.2**	**1.3**	**1.4**	**2**	**1.5**
	MCBP 34	**2.0**	**1.9**			
	XDN2438	**4.8**	6.0	6.0	6.8	6.4
	XDN0146	4.6	**5.1**	5.1	5.7	5.8

[a, b] stations with the same letter are co-located

NCCA status: One station was sampled for National Coastal Condition Assessment during August 2010, and chlorophyll *a* met the seagrass objective (15 µg/L) at 12.71 µg/L.

Continuous monitoring Status: A continuous monitor was deployed on Turville Creek during only one year of this report's time period (2007). It shows the seagrass threshold failed 54% of the time from March – November (1.4% and 10.0 percent for 50 and 30 µg/L thresholds, respectively).

Table 4.2.7 Annual percent failure of chlorophyll endpoints.

Site	Threshold	2007
Turville Creek TUV0021	**CHL > 50**	**1.4%**
	CHL > 30	10.0%
	CHL > 15	**53.6%**
	CHL > 7.5	86.9%

The calibration data from the Turville Creek continuous monitor show the predicted value exceeded the extracted value in nearly all instances, particularly during June and September, when the sonde was left in place for more than two weeks.

Figure 4.2.7 Comparison of extracted chlorophyll *a* vs fluorescence and predicted temperature-corrected fluorescence chlorophyll values in Turville Creek (2007).

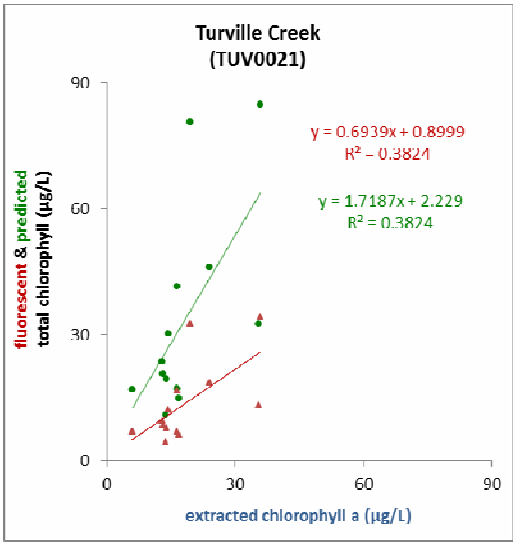
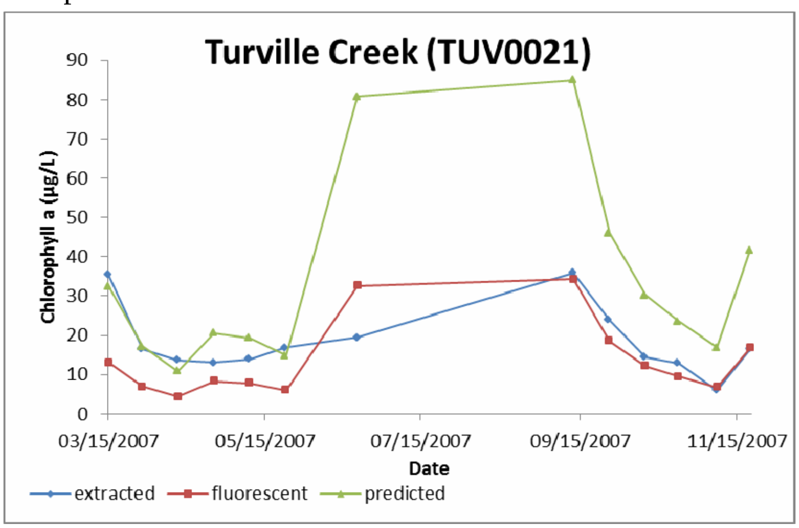


Figure 4.2.8 Comparison of chlorophyll *a* values measured by fluorescence probe, extracted and temperature corrected predicted values in Turville Creek.



<u>TMDL Status</u>: Achievement of the total maximum daily load endpoints in Isle of Wight Bay ranged from 0-5.6% in tributaries with a 50 µg/L threshold and 11-44% failure in open bay sites with a 15 µg/L threshold (Table 4.2.16). Exceedance of the 50 µg/L endpoint did not occur at any of the fixed stations (Table 4.2.16).

Sinepuxent Bay
Fixed Station Status: All fixed stations met seagrass thresholds (Table 4.2.8 and Figure 4.2.2).

Table 4.2.8 Rolling three year chlorophyll *a* status at stations in the Sinepuxent Bay watershed (2007-2013).

3-year medians of chlorophyll *a* (µg/L) in Sinepuxent Bay						
	STATION	2007-09	2008-	2009-11	2010-12	2011-13
West OC Harbor	ASIS 1	**4.9**	**3.9**	4.6	**4.6**	**4.6**
Sinepuxent Bay	ASIS 17	**4.7**	**4.6**	5.4	**5.7**	**5.9**
	ASIS 18	**4.1**	**3.2**	4.4	**4.9**	**5.5**
	MCBP 31	**2**	**2.7**	**4.3**	**4.3**	**3.1**
	ASIS 2	**4.1**	**3.9**	4.1	**4.6**	**4.6**
	MCBP 10	6.2	4.3	**4.2**	**4.5**	5.3
	ASIS 16	7.6	5.2	5.2	**3.7**	**3.7**

NCCA status: There were no stations located in Sinepuxent Bay.

Continuous monitoring Status: ASIS maintains a continuous monitor at a tide gauge station near the Verrazano Narrows Bridge (TS1). Data available from 2009-13 shows that total chlorophyll increased dramatically after 2010. 2012 was a particularly poor year, where total chlorophyll failed the threatened threshold (50 µg/L) nearly 30% of the time and the seagrass threshold (15 µg/L) nearly 90% of the time. Performance improved in 2013, but failure rates remained elevated relative to 2009-2010.

Table 4.2.9 Annual percent failure of chlorophyll endpoints in Sinepuxent Bay (2007-2013).

Site	Threshold	2007	2008	2009	2010	2011	2012	2013
Verezzano Narrows Bridge ASIS TS1	**CHL > 50**	**No Data**	**No Data**	**4.1%**	**2.1%**	**3.6%**	**29.9%**	**1.1%**
	CHL > 30			5.7%	3.1%	25.7%	57.1%	17.9%
	CHL > 15			**25.7%**	**8.7%**	**44.1%**	**87.8%**	**65.9%**
	CHL > 7.5			49.9%	51.1%	59.1%	96.0%	96.7%

Simultaneous grab samples for chlorophyll *a* extraction were not collected at TS1, therefore calibration was not done to predict extracted chlorophyll *a* using continuous monitor fluorescent total chlorophyll and temperature data.

TMDL Status: Achievement of the total maximum daily load 15 µg/L endpoint was achieved at 100% of sites and an improvement from the 2001-2004 assessment (Table 4.2.16). There were no exceedences of the 50 µg/L chlorophyll *a* target (Table 4.2.16).

Newport Bay
Fixed Station Status: In the lower, open bay, the seagrass threshold was met at three sites (ASIS3, ASIS4, XCM4878). While many tributary stations did meet this threshold, many of these are far upstream above the turbidity/chlorophyll maximum and low chlorophyll concentrations are to be expected.

Table 4.2.10 Rolling three year medians of chlorophyll *a* (µg/L) at stations in the Newport Bay watershed during seagrass growing season (March – November).

3-year medians of chlorophyll *a* (µg/L) in Newport Bay						
	STATION	2007-09	2008-10	2009-11	2010-12	2011-13
Trappe Creek	KIT0015	3.3	3.6	**3.9**	**4.1**	**4.5**
	BOB0001	6.3	7.1	7.2	8.3	8.0
	MCBP 4					**3.9**
	MCBP 23	6.9	5.9	4.5	5.1	4.5
	TRC0059[a]	11.7	9.3	13.2	8.7	12.0
	MCBP 35[a]	**4.4**	**5.5**	6.9	6.9	6.8
	TRC0043	43.0	44.9	48.1	56.1	56.1
Ayres Creek	AYR0017[b]	44.7	43.8	38.3	39.3	50.2
	MCBP 33[b]	24.7	22.6	17.3	33.4	31.7
Newport Creek	BMC0011	**0.9**	**0.9**	0.8	**1.2**	**0.9**
	NPC0031	32.6	19.9	33.1	32.4	30.3
	NPC0012	22.4	25.6	18.2	25.6	22.4
Newport Bay	ASIS 4	16.3	14.6	11.9	11.2	10.2
	MCBP 15	13.5	8.1	6.3	6.8	10.2
	XCM4878	11.7	13.4	14.3	13.4	**11.0**
	ASIS 3	12.9	**11.4**	9.5	9.5	8.6
Bassett Creek	MCBP 28	**0.9**	**1.0**	**1.4**	**1.7**	**1.4**
Marshall Creek	MSL0011[c]	32.6	34.4	32.0	28.1	29.6
	MCBP 12[c]	22.0	19.8	16.1	19.0	18.0

[a, b, c]: stations with the same letter are co-located

<u>NCCA status</u>: No stations in Newport Bay were sampled during NCCA 2010.

<u>Continuous monitoring Status</u>: During March through November of 2007, 2008, and 2012, the Newport Creek continuous monitor showed total chlorophyll concentrations failing the SAV threshold (15 µg/L) over 80% of the time. Performance was somewhat better at higher concentration thresholds (30 and 50 µg/L thresholds). Failure of the 30 µg/L threshold ranged from 12 to 50%, with the highest rate in 2008 and the lowest in 2013. Percent failure at 50 µg/L was relatively low compared to Bishopville Prong, ranging from 0.5 to 17.5% of the time (Table 4.2.11).

Table 4.2.11 Annual percent failure of chlorophyll criteria in Newport Creek (2007-13)

Site	Threshold	2007	2008	2009	2010	2011	2012	2013
Newport Creek NPC0012	**CHL > 50**	**4.7%**	**12.5%**	**10.3%**	**8.1%**	**7.6%**	**17.5%**	**0.5%**
	CHL > 30	25.4%	55.1%	22.8%	27.9%	33.1%	39.1%	12.5%
	CHL > 15	**86.4%**	**88.2%**	**61.9%**	**73.8%**	**61.6%**	**85.0%**	**51.4%**
	CHL > 7.5	99.3%	99.5%	92.9%	99.4%	93.2%	97.8%	93.3%

Figure 4.2.9 Comparison of extracted chlorophyll *a* vs fluorescence and predicted temperature-corrected fluorescence chlorophyll values in Newport Creek (2007-2013).

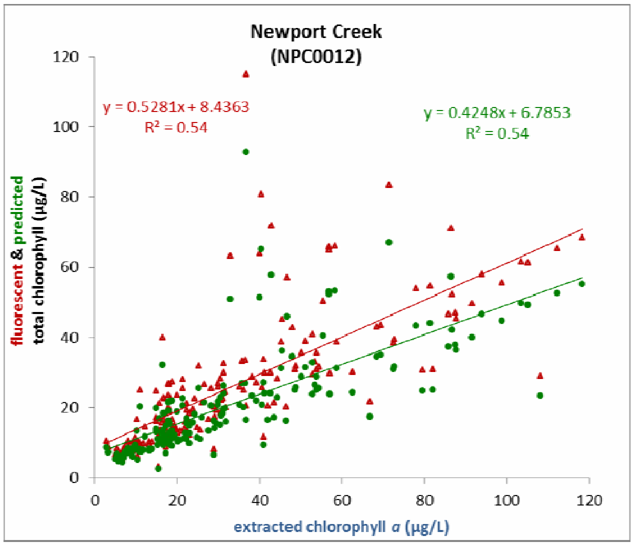
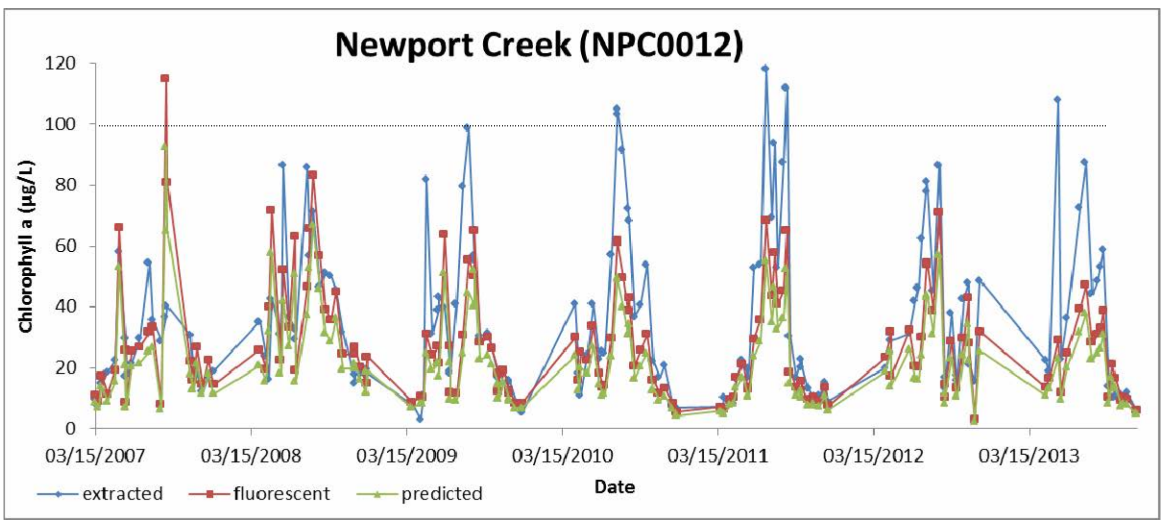


Figure 4.2.10 Comparison of chlorophyll *a* values measured by fluorescence probe, extracted and temperature corrected predicted values in Newport Creek.



TMDL Status: Achievement of the total maximum daily load endpoints in Newport Bay ranged from 0-3% at sites with 50 µg/L threshold and 19% at the one site with a 15 µg/L threshold (Table 4.2.16). The continuous monitor at Newport Creek showed 50 µg/L was exceeded most years (Figure 4.2.10).

Chincoteague Bay

Fixed Station Status: All sites met seagrass threshold of 15 µg/L, with almost all sites less than 7.5 µg/L (Figure 4.2.2).

Table 4.2.12 Rolling three year medians of chlorophyll *a* (µg/L) at stations in the Chincoteague Bay watershed during seagrass growing season (March – November).

3-year medians of chlorophyll *a* (µg/L) in Chincoteague Bay							
		STATION	2007-09	2008-10	2009-11	2010-12	2011-13
Maryland	Open Bay	XCM1562	8.8	6.4	9.2	8.8	6.2
		XCM0159	7.2	7.5	9.8	8.5	7.7
		ASIS 5	9.3	7.6	7.5	7.5	**4.7**
		XBM5932	6.6	5.9	8.9	7.5	6.4
		MCBP 18	6.4	4.9	**3.5**	**3.8**	**3.2**
		ASIS 6	6.8	7.7	**6.5**	**6.1**	**3.3**
		XBM8149	8	9.2	7.8	8.2	8.1
	Johnson Bay	ASIS 7	6.4	5.8	5.2	6.4	**5.2**
		ASIS 14	**4.7**	**3.1**	**4.8**	**4.2**	**2**
	Open Bay	XBM3418	**5.6**	**4.5**	**6.3**	**5.9**	**2.5**
		ASIS 15	**4.4**	**4.8**	**3.9**	**3.9**	**2.6**
	Johnson	MCBP 24				5.4	5.4
	Open bay	XBM1301	**3.1**	**2.9**	**3.8**	**4.6**	**2.2**
Virgina		ASIS 9	**3.1**	**3.1**	**2.9**	**2.9**	**2.9**
		MCBP 29				4.9	4.9
		ASIS 10	**2.5**	**3**	**2.7**	**2.9**	**2.7**
		ASIS 8	**2.8**	**2.3**	**2.5**	**2.6**	**2.5**
		ASIS 11	**4.6**	**4.2**	**5.2**	**5.2**	**5.2**
		ASIS 12	**4.3**	**3.2**	**4.4**	**4.7**	**4.7**
		ASIS 13	5.6	5.4	**5.4**	**4.7**	**5**
	Parker Bay	MCBP 27	**4.4**	**4**	**2.3**	**3.1**	**3.1**

NCCA status: Two stations were sampled for Natioanl Coastal Condition Assessment during 2010. Chlorophyll *a* met the seagrass objective (15 µg/L) at NCCA10-1629 (12.71 µg/L). At NCCA10-1633, chlorophyll *a* (3.7 µg/L) was better than the seagrass objective (7.5 µg/L).

Continuous monitoring status: Continuous monitoring data collected at Public Landing and Green Run Bay showed more chlorophyll failures, with the percent failure of the seagrass threshold (15 µg/L) as much as 94% of the time in 2012. The best attainment rate occurred during 2013 at Public Landing, with a failure rate of 2%. Failure at the 50 µg/L threshold was a rare event (<12%) at that location, and did not occur during 2011 or 2013.

Table 4.2.13 Annual failure of chlorophyll criteria at Public and Tingles Landings

Site	Threshold	2007	2008	2009	2010	2011	2012	2013
Public Landing XBM8828	**CHL > 50**	**11.1%**	**4.9%**	**5.7%**	**2.0%**	**0.0%**	**0.3%**	**0.0%**
	CHL > 30	31.8%	19.5%	11.6%	6.2%	0.0%	3.3%	0.0%
	CHL > 15	**57.1%**	**52.9%**	**30.6%**	**37.5%**	**4.0%**	**21.6%**	**2.2%**
	CHL > 7.5	81.2%	80.7%	58.0%	69.7%	47.7%	63.1%	34.3%
Tingles Landing ASIS TS2	**CHL > 50**	**No Data**	**No Data**	1.2%	0.5%	1.4%	63.0%	0.6%
	CHL > 30			7.9%	0.7%	5.8%	83.5%	2.1%
	CHL > 15			48.5%	17.3%	24.3%	93.8%	17.4%
	CHL > 7.5			67.7%	73.1%	50.7%	99.2%	65.2%

Figure 4.2.11 Comparison of extracted chlorophyll *a* vs fluorescence and predicted temperature-corrected fluorescence chlorophyll values in Chincoteague Bay (2007-2013).

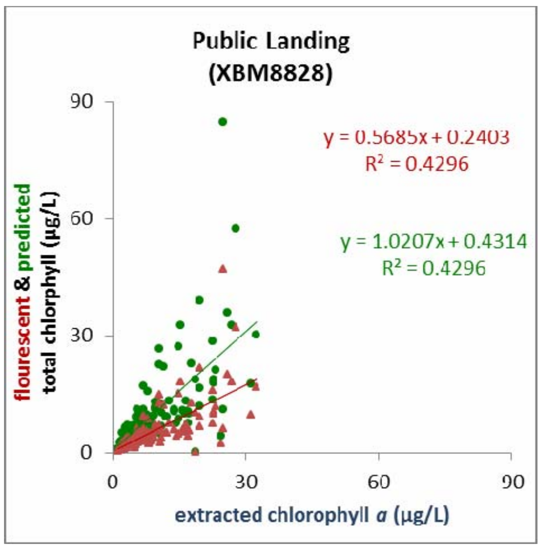
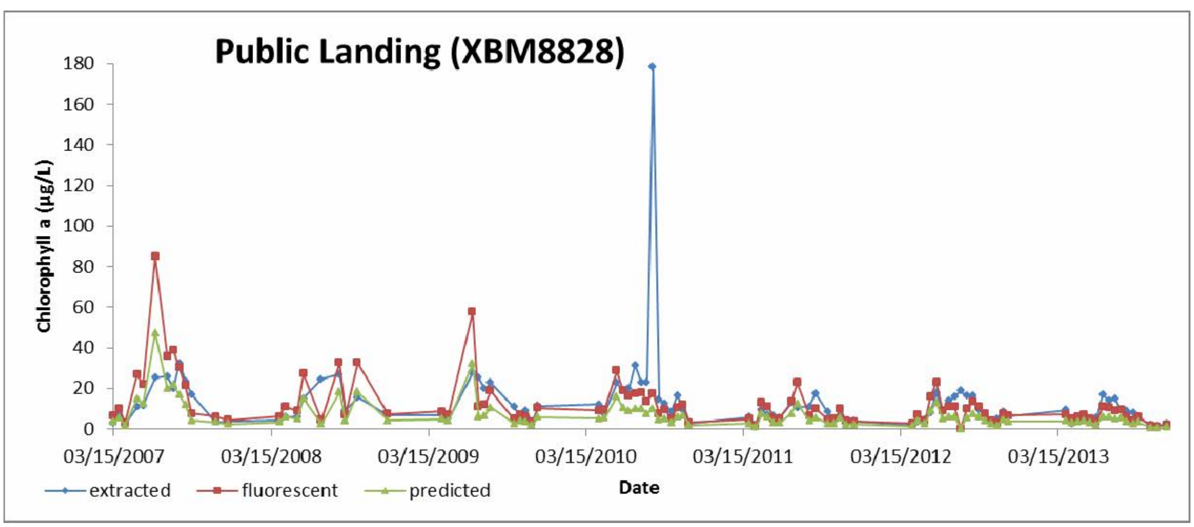


Figure 4.2.12 Comparison of chlorophyll *a* values measured by fluorescence probe, extracted and temperature corrected predicted values in Greys Creek.



TMDL Status: Achievement of the total maximum daily load thresholds and the 50 μg/L endpoint in Chincoteague Bay were met at all sites (Table 4.2.16).

Results: Trends in algae abundance
Few linear trends were observed in chlorophyll *a* concentration in any Coastal Bays segment. Among those, improving trends were found at four Assawoman Bay open bay stations and one in St. Martin River, while declining trends were found at one Newport Bay (Bottle Branch) and two Chincoteague Bay stations located in the Virginia portion of the bay near Chincoteague Island (Table 4.2.14). Many significant non-linear trends were found, and all were changing from degrading to improving during the analysis timeframe (Table 4.2.15).

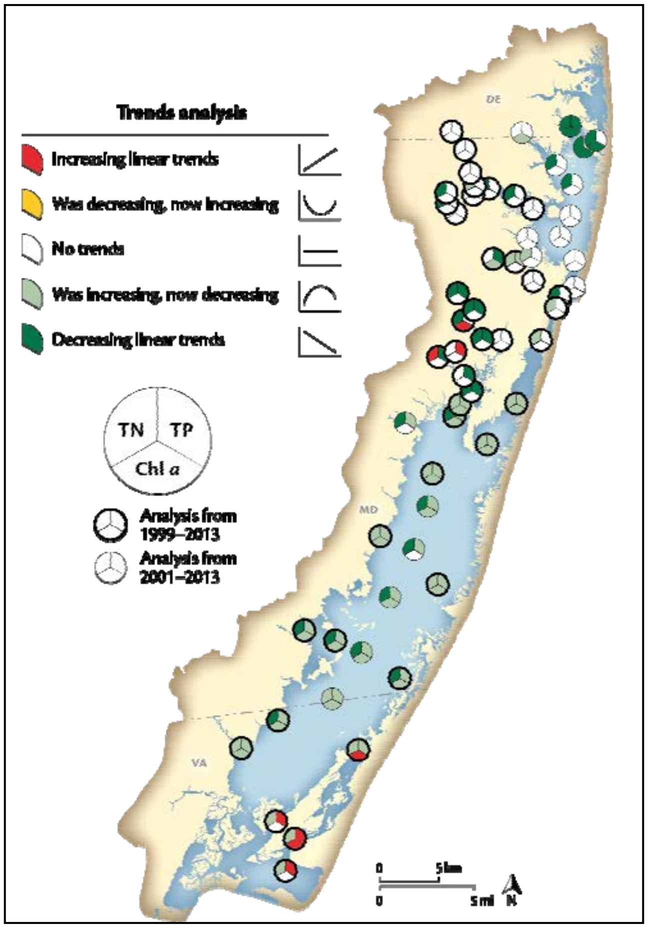
Table 4.2.14 Significant linear trend results for chlorophyll *a*. Cells shaded green are significantly improving while cells shaded pink are significantly degrading.

Station	p-value	slope	parameter	segment
XDN7261	0.0000	-0.769	CHLA	Assawoman Bay
XDN6454	0.0000	-0.6022	CHLA	
XDN7545	0.0073	-0.5696	CHLA	
MCBP 1	0.0000	-0.735	CHLA	
ASIS 8	0.0050	0.1148	CHLA	Chincoteague Bay
ASIS 12	0.0009	0.1753	CHLA	
BOB0001	0.0024	0.2783	CHLA	Newport Bay
MCBP 11	0.0000	-3.1343	CHLA	St. Martin R

Table 4.2.15 Significant non-linear trend results for chlorophyll *a*. Cells shaded green are significantly improving while cells shaded pink are significantly degrading.

Station	trend type	critical date	segment
GET0005	inverted U	18Jul2007	Assawoman Bay
MCBP 13	inverted U	29Sep2004	St. Martin River
TUV0034	inverted U	12Nov2004	Isle of Wight
ASIS 2	inverted U	18Jul2007	Sinepuxent Bay
MCBP 10	inverted U	24Jul2007	
ASIS 16	inverted U	26Oct2006	
XCM4878	inverted U	03Feb2007	Newport Bay
ASIS 3	inverted U	10Jan2006	
MCBP 12	inverted U	05Aug2007	
XCM1562	inverted U	24Mar2007	Chincoteague Bay
XCM0159	inverted U	05Jun2007	
ASIS 5	inverted U	21Jan2006	
MCBP 18	inverted U	17Jan2006	
ASIS 6	inverted U	20Sep2005	
XBM8149	inverted U	02Apr2007	
ASIS 7	inverted U	25May2005	
ASIS 14	inverted U	17Aug2005	
XBM3418	inverted U	08Sep2005	
ASIS 15	inverted U	22Sep2005	
XBM1301	inverted U	16Jan2006	
ASIS 9	inverted U	09May2006	
ASIS 10	inverted U	29Dec2005	

Figure 4.2.13 Chlorophyll *a* trends at Marylan Department of Natural Resources and Assateague Island National Seashore stations (1999-2013 or 2001-2013). Linear trends are primary, if there was no linear trend detected then non-linear trend analyses were checked for significant trends.



Assawoman Bay
Four linearly improving trends and one non-linear improving chlorophyll trend (Greys Creek, GET0005) were detected is Assawoman Bay (Figure 4.2.13).

St. Martin River
One linear improving (MCBP 11) and one non-linear chlorophyll trend was detected at the mouth of Bishopville Prong (MCBP 13), otherwise no chlorophyll trends were detected (Figure 4.2.13).

Isle of Wight Bay
One improving non-linear trend was found in the upper reach of Turville Creek (TUV0034), otherwise no chlorophyll trends were detected (Figure 4.2.13).

Sinepuxent Bay
Two improving non-linear chlorophyll trends were found in the southern part of the bay while no significant trends were detected in northern areas (Figure 4.2.13).

Newport Bay
Improving non-linear trends were found at two open bay sites (XCM4878, ASIS 3), and at 1 tributary site (MCBP 12 – Marshall Creek). A degrading linear trend was found at one upper tributary station (BOB0001 – Bottle Branch). (Figure 4.2.13)

Chincoteague Bay
Two degrading linear, chlorophyll trends were found near Chincoteague Island (ASIS 8 and 11) and 12 significantly improving, non-linear trends in chlorophyll were found in Chincoteague Bay (Figure 4.2.13).

Summary
Current status analyses show chlorophyll levels are suitable for seagrasses in the bays (79.5% of sites passed seagrass chlorophyll threshold) and elevated in many tributaries. Overall, trends show improving chlorophyll concentrations or no trend at all.

The seagrass chlorophyll threshold (15ug/L) was met at a majority of sites in Assawoman, Isle of Wight, Sinepuxent and Chincoteague bays; while the St. Martin River and tributaries of Newport Bay failed during the most recent assessment period (2011-2013). The STAC chlorophyll threshold (>50ug/L) showed eutrophic conditions are present in Bishopville Prong, Trappe Creek and Ayres Creek. Surprisingly the August 2010 snapshot of chlorophyll by the National Coastal Assessment showed similar results.

The relationships of measured fluorescent and predicted values, suggesting that percent failure for chlorophyll criteria may actually have been higher during most years. Intensive temporal monitoring shows the duration of blooms can be very long in these areas. Even Chincoteague Bay showed intense blooms when 30-57% of samples were >15 µg/L at Public Landing and 17-94% of values at Taylor's Landing. Continuous monitors should be placed in all bay segments to better understand duration of blooms; at present only Isle of Wight Bay does not have a deployed continuous monitor.

Chlorophyll criteria for TMDL analyses use a different metric than the MCBP STAC analyses. Applying this analysis to the same dataset used to determine if STAC thresholds were achieved, a different picture emerges of areas meeting or failing objectives (Figure 4.2.16). The TMDL analyses show that chlorophyll endpoints are not met ($\geq$5% of values above threshold) at 44% of the sites in the Coastal Bays. This analysis relates better to areas with oxygen problems (see Chapter 4.3).

Trend analyses show significantly improving trends at 27 of 79 sites (34%), throughout the Coastal Bays system. Improving linear trends were found mostly in Assawoman Bay, while non-linear trends showed improvements in many areas, especially Chincoteague Bay. Three significant degrading chlorophyll trends were found – two in southern Chincoteague Bay and the third in Bottle Branch, a tributary of Newport Bay suggesting nutrient sources need to be reduced in these areas.

Despite many areas failing nutrient thresholds in the Coastal Bays, chlorophyll values were generally good in the open bays. This could be because much of the algal biomass (organic matter) produced in the tributaries is deposited within these areas (see Chapter 5.1). Another explanation may be that nutrients are sequestered in or utilized by other forms such as benthic planktonic algae, macroalgae, and seagrasses instead of water column phytoplankton. We recommend that all primary producers be monitored in a coordinated program in order to best understand the total impacts of nutrient inputs.

Table 4.2.16 Total maximum daily load, TMDL, chlorophyll analysis (2001-2004 vs 2011-2013) indicating the percent of time chlorophyll *a* levels are not meeting thresholds for TMDL endpoint. Red box indicates greater failure rate in more recent period (2011-2013) compared with baseline analysis (2001-2004).

Sub-basin	Station Name	Threshold (Endpoint)	Growing season % > Threshold		Annual % > Threshold	
			2001-2004	**2011-2013**	2001-2004	**2011-2013**
Assawoman Bay	XDN4851	>15	45.83	**33.3**	27.97	**17.1**
	XDN5737	>50	0	**5.6**	0	**2.9**
	XDN6454	>15	70.83	**27.8**	41.86	**14.3**
St. Martin River	BSH0008	>50	39.13	**55.6**	26.19	**33.3**
	SPR0002	>50	25	**11.1**	15.56	**8.3**
	SPR0009	>50	43.48	**33.3**	27.91	**19.4**
	XDM4486	>50	50	**70.6**	41.86	**48.5**
	XDM4797	>50	8.33	**22.2**	11.11	**16.7**
	XDN3724	>50	0	**0.0**	4.55	**0.0**
	XDN4312	>50	4.17	**2.8**	6.67	**1.4**
Isle of Wight Bay	TUV0011	>50	4.17	**0.0**	2.22	**0.0**
	TUV0019	>50	8.33	**5.6**	4.26	**2.8**
	MKL0010	>50	4.17	**0.0**	2.22	**0.0**
	XDN0146	>15	8.33	**11.1**	6.67	**11.1**
	XDN2340	>15	20.83	**22.2**	13.33	**13.9**
	XDN2438	>15	12.50	**11.1**	8.89	**11.1**
	XDN3445	>15	29.17	**44.4**	17.78	**22.2**
Newport Bay	AYR0017	>50	37.5		25	
	XCM4878	>50	4	**0**	2.33	**0**
	ASIS 3	<15	50	**19.4**	27.66	**33.3**
	ASIS 4	>50	4.17	**2.8**	2.17	**5.6**
Sinepuxent Bay	ASIS 1	<15	8.33	**2.8**	4.26	**5.6**
	ASIS 2	<15	12.5	**5.6**	6.38	**11.1**
	ASIS 16	<15	20.83	**0**	10.64	**0**
	ASIS 17	<15	12.5	**8.3**	6.38	**11.1**
	ASIS 18	<15	12.5	**5.6**	6.38	**0**
Chincoteague Bay, MD	XBM1301	>50	4.35	**0.0**	2.27	**0.0**
	XBM3418	>50	0	**0.0**	0	**0.0**
	XBM5932	>50	0	**0.0**	0	**0.0**
	XBM8149	>15	56.52	**13.9**	29.55	**7.1**
	XCM0159	>15	39.13	**19.4**	20.45	**10.0**
	XCM1562	>50	0	**0.0**	0	**0.0**
Chincoteague Bay, VA	ASIS 5	<15	33.33	**2.8**	16.67	**5.6**
	ASIS 6	<15	12.5	**0**	6.25	**0**
	ASIS 7	<15	37.5	**5.6**	19.15	**11.1**
	ASIS 8	<15				
	ASIS 14	<15	4.35	**0**	2.17	**0**
	ASIS 15	<15	0	**0**	0	**0**

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Chapter 4.3

Dissolved oxygen status and trends in the Maryland Coastal Bays

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Abstract
Although the Coastal Bays are shallow lagoons that typically do not stratify, low dissolved oxygen (DO) concentrations were observed in some areas. Daytime measurements showed infrequent dissolved oxygen concentrations below 5 mg/L during the summer at some locations. Diel data from continuous monitors showed oxygen values less than 5 mg/L frequently in tributaries (20-60% of the time), but less often in the open bays. DO concentrations below 3 mg/L were observed infrequently by monthly daytime sampling, however diel sampling results revealed more pervasive and lengthy conditions of such extreme low DO events, often occurring at night and early morning.

Introduction
Eutrophication and it's impacts to living resources was identified in the Maryland Coastal Bays Characterization Report as the most pressing environmental issue facing Maryland's Coastal Bays. As a result, the Scientific and Technical Advisory Committee (STAC) recommended that the initial focus of the monitoring plan be on nutrient and sediment inputs to the Coastal Bays and their impacts on living resources (Wazniak 1999). DO concentration in water is often used to gauge the overall health of the aquatic environment and is needed to maintain suitable fisheries habitat. Concentrations often vary with depth, and the lowest values are found near the bottom. When excessive amounts of algae die and sink to the bottom. The process of algal decomposition by bacteria consumes oxygen. The resulting low levels of oxygen that result can impair the feeding, growth and reproduction of aquatic life in the bays. Animals that cannot move about easily may die. Fish and crabs generally detect and avoid areas with low DO. Oxygen concentrations that trigger avoidance (around 5 mg/L for most species) tend to be two to three times higher than lethal DO levels.

Daytime DO measurements are problematic in a non-stratified embayment. Because the Coastal Bays are shallow and generally well-mixed bays, low DO typically does not persist for long periods of time and cannot usually be detected by daytime measurement alone. Also, exceedingly high daytime DO levels that result from phytoplankton blooms often surpass threshold levels, and then plummet at night as photosynthesis ceases and respiration continues. Daily oxygen fluctuations in the Coastal Bays vary between one and six mg/L/day depending on season and chlorophyll abundance (Wazniak 2002). Minimum DO levels occur in the early to mid-morning, and monitoring programs typically collect samples hours later, between 9 a.m. and 2 p.m. Other factors that may impact the use of daytime DO as a primary indicator of eutrophic impacts include naturally low DO in areas with extensive marshes (especially at ebb tide) and areas of abundant benthic algae. Additionally, some areas have high sediment oxygen demand which contributes to low water column oxygen.

Maryland state water quality criteria require a minimum DO concentration of 5 mg/L at all times (Code of Maryland, COMAR, 1995). This water quality standard is needed for the following aquatic target species in the Coastal Bays: hard clam (*Mercenaria mercenaria*), alewife (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), white perch (*Morone americana*) and striped bass (*Morone saxatilis*). Blue crabs (*Callinectes sapidus*), bay anchovies (*Anchoa mitchelli*); alewife and blueback herring juveniles need a minimum of 3 mg/L DO. More tolerant species such as spot (*Leiostomus xanthurus*) and Atlantic menhaden (*Brevoortia tyrannus*) need a minimum of 2 mg/L and 1.1 mg/L, respectively, before significant mortalities occur (Funderburk *et al.* 1991). While these species may survive at such low oxygen values, they will not grow or reproduce.

Data Sets

Oxygen concentrations at fixed sampling stations were monitored monthly during the day by the DNR, the National Park Service, Assateague Island National Seashore (ASIS), and volunteers with MCBP (DNR 2014a and 2014b, ASIS 2001) (Maryland Department of Natural Resources 2014).

Continuous monitors have been operated by DNR at five sites between 2007 and 2013, and by ASIS at two sites between 2009 and 2013. Continuous monitors collect data at 15-minute intervals.

During August 2010, a single oxygen profile was collected at 25 fixed sites for U.S. Environmental Protection Agency's (EPA) National Coastal Condition Assessment (NCCA).

Management Objective: To maintain suitable fisheries (all benthic community) habitat.

DO Indicator 1: Minimum of 5 mg/L during diurnal (day)
DO Indicator 2: Minimum of 3 mg/L at any time

Analyses

Status Analyses:

1. Fixed Monitoring Data: A 98th percentile dissolved oxygen value was determined for the summer season (June through September) for rolling three-year periods from 2007-2013 for each fixed station monitoring station (Figure 4.3.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed threshold values based on living resources indicators (see Management Objective above). Based on these criteria, attainment categories were determined (Table 4.2.1). Each calculated value was compared to its category cut-off values using the non-parametric Wilcoxon sign-rank test. Those values that were significantly different at p=0.01 from both category cutoffs were considered statistically significant overall.

2. Continuous Monitoring Data: DO concentrations from continuous monitors were

analyzed annually for the percent time the concentrations fell below the 5 and 3 mg/L thresholds.

3. National Coastal Condition Assessment (NCCA) 2010 data: During August 2010, one visit was made to each of 25 stations (Figure 4.3.2), providing a snapshot of water quality conditions. Bottom DO values were placed into STAC attainment categories (Table 4.3.1).

4. Total Maximum Daily Load (TMDL) analyses: Percent time dissolved oxygen failed the 5mg/L threshold (June – August).

Trend Analysis:

Trends were not determined for oxygen due to the temporal variability of sample collection. The time of day when measurements were taken was not consistent within or among sampling programs.

Figure 4.3.1 Location of fixed station monitoring sites for Maryland Department of Natural Resources, Assateague Island National Seashore and Maryland Coastal Bays Volunteer monitoring programs.

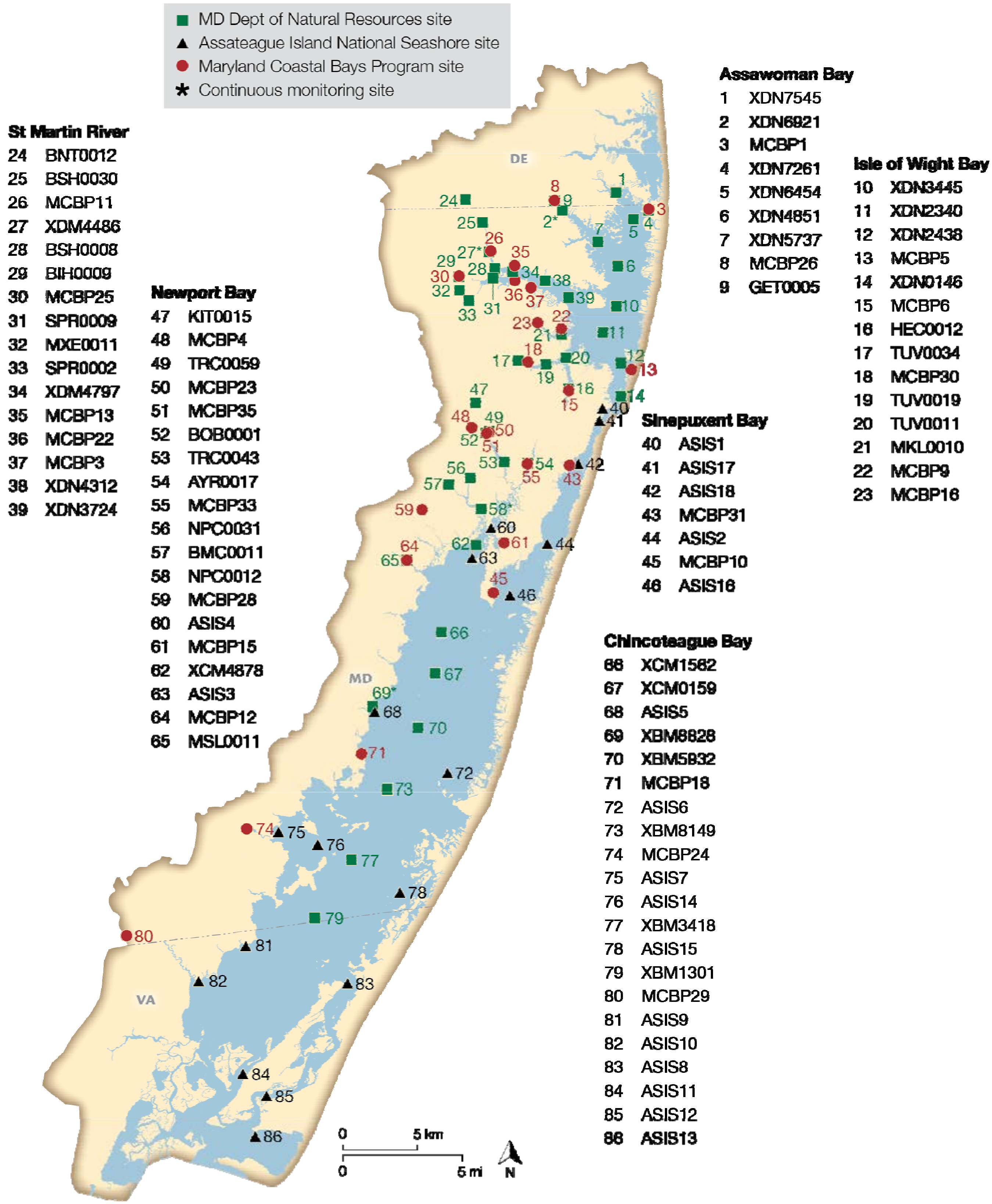

Figure 4.3.2 Location of 2010 National Coastal Condition Assessment and Maryland Coastal Bays benthic sampling sites.

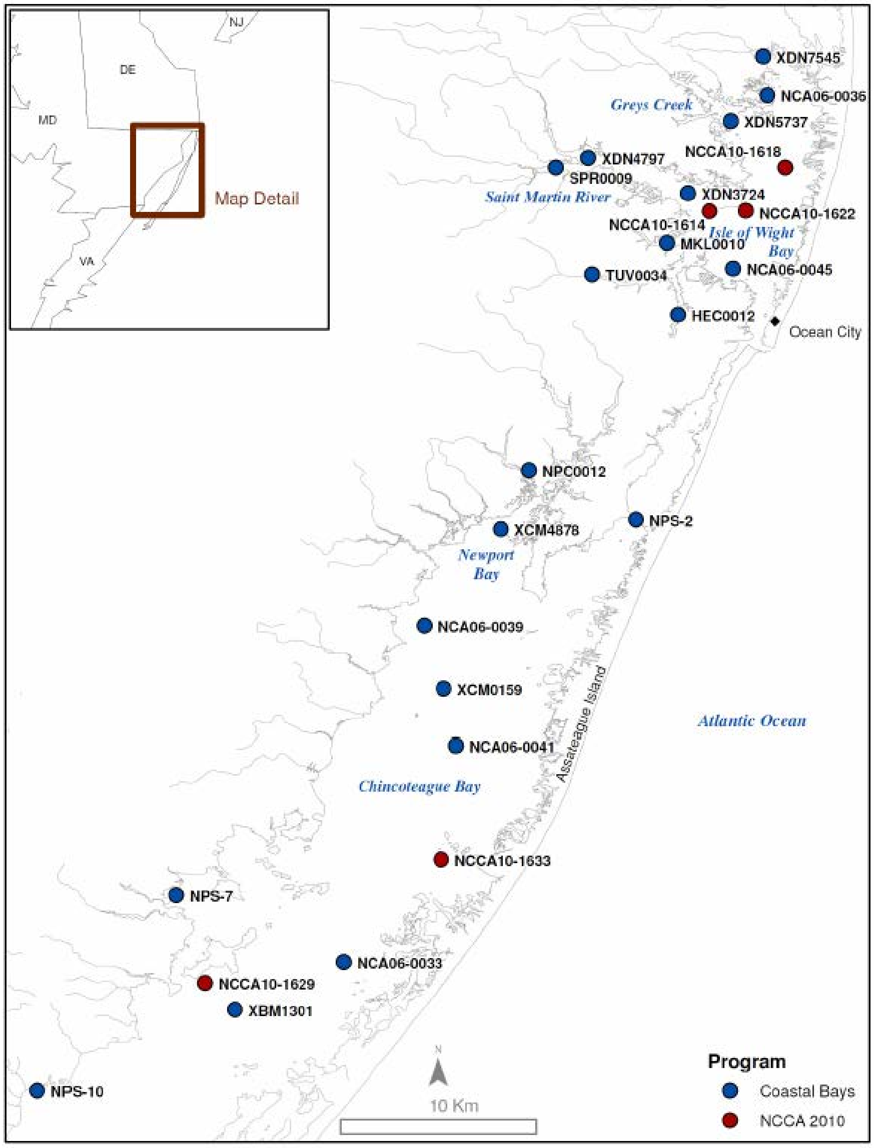

Table 4.3.1 Category values for dissolved oxygen concentration in the Maryland Coastal Bays. Bolded values are living resources and dissolved oxygen indicator values.

Category	Dissolved oxygen values for category
Better than living resources objective	> 7 mg/L
Meets living resources objective	6 - 7 mg/L
Borderline living resources objective	5 - 6 mg/L
Living resources threatened	**3 - 5 mg/L**
Does not meet objectives	< 3 mg/L

Results: Status of dissolved oxygen

Figure 4.3.3 The status of dissolved oxygen in the Maryland Coastal Bays (2001-2013).

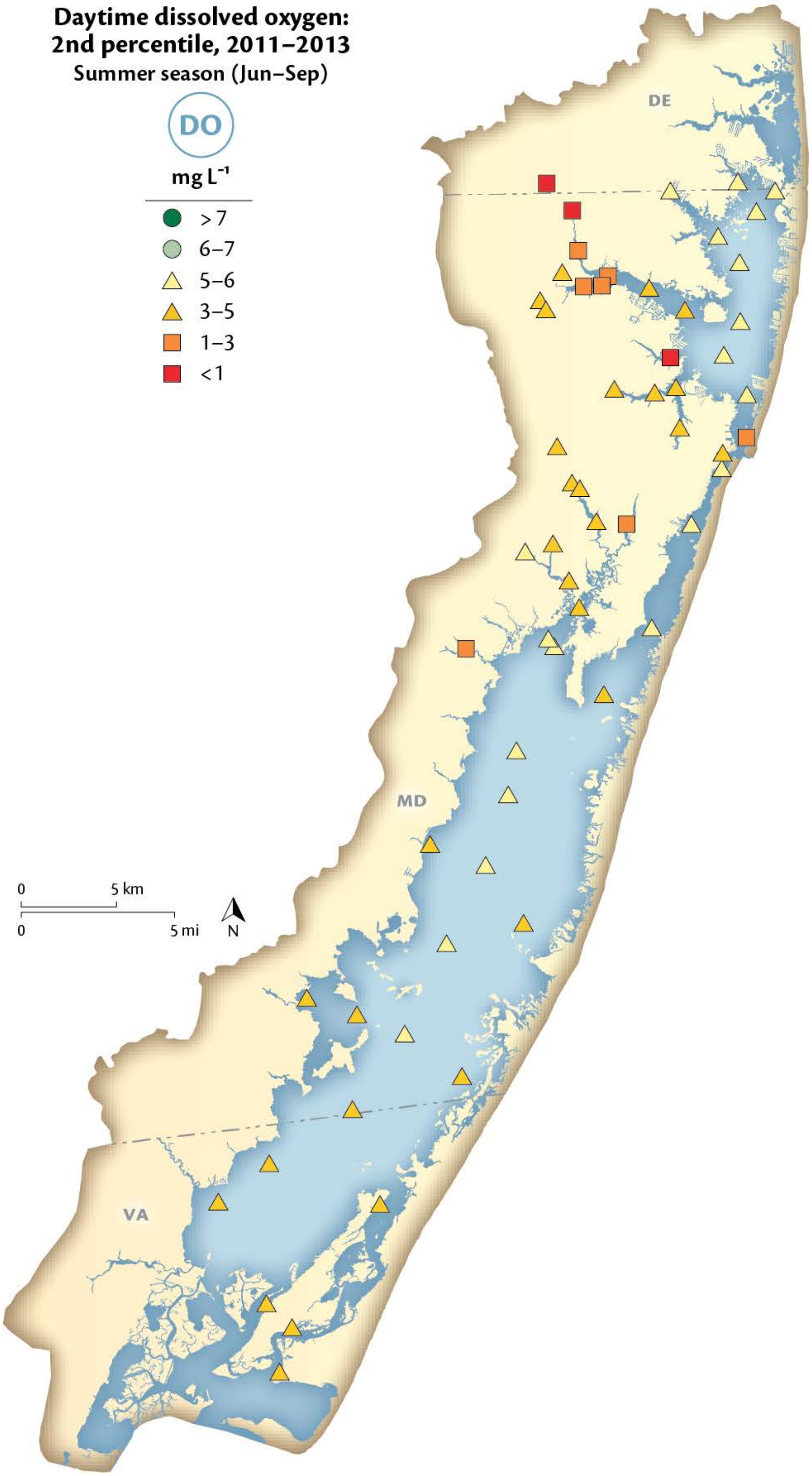

Table 4.3.2 Annual percent of time summer dissolved oxygen (June – September) threshold levels were not met (e.g. failure) at continuous monitoring stations in the Maryland Coastal Bays (2007 – 2013).

	Station	Threshold Level	2007	2008	2009	2010	2011	2012	2013
Greys Creek	XDN6921	DO<5	NS	31.5%	43.1%	43.9%	44.9%	33.7%	48.1%
		DO<3	NS	9.6%	18.4%	17.8%	18.0%	8.6%	18.8%
Bishopville Prong	XDM4486	DO<5	48.9%	39.6%	50.5%	40.7%	55.8%	43.8%	49.2%
		DO<3	24.7%	15.0%	24.6%	16.1%	26.4%	18.2%	27.3%
Turville Creek	TUV0021	DO<5	42.4%	NS	NS	NS	NS	NS	NS
		DO<3	13.1%	NS	NS	NS	NS	NS	NS
Newport Creek	NPC0012	DO<5	42.2%	30.6%	38.8%	39.3%	41.8%	28.7%	21.3%
		DO<3	11.1%	4.5%	7.3%	7.8%	10.2%	2.6%	0.5%
Public Landing	XBM8828	DO<5	14.5%	18.4%	9.2%	15.9%	18.6%	16.4%	10.9%
		DO<3	0.3%	0.6%	0.7%	1.2%	0.4%	0.1%	0.6%
Sinepuxent at bridge	ASIS TG1	DO<5	NS	NS	43.6%	43.7%	28.0%	24.3%	5.2%
		DO<3	NS	NS	6.2%	12.6%	4.9%	0.2%	0.02%
Tingle Island	ASIS TG2	DO<5	NS	NS	45.4%	31.2%	30.1%	11.5%	1.3%
		DO<3	NS	NS	9.2%	8.7%	1.8%	0.6%	0.1%

NS – not sampled

Assawoman Bay

Fixed Station Status: All stations are borderline or fail the minimum living resources threshold (5 mg/L) (Table 4.3.3).

Table 4.3.3 Rolling three year assessment of 98th percentile of dissolved oxygen (mg/L) during the summer months (June-Sept) in Assawoman Bay

Area	STATION	07-09	08-10	09-11	10-12	11-13
Greys Creek	M26			0.6	0.6	0.6
	GET0005	1.3	1.3	2.7	2.7	3.5
Fenwick Ditch	XDN7261	4.6	4.4	4.0	4.0	4.0
	MCBP 1		3.7	3.7	**3.7**	3.8
Assawoman Bay	XDN4851	5.2	5.2	5.0	5.0	4.7
	XDN5737*	5.1	5.0	4.5	4.5	4.5
	XDN6454	4.0	4.0	4.0	4.4	4.0
	XDN7545*	3.9	3.9	3.8	3.8	3.8

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring Status: The continuous monitoring station on Grey's Creek failed the oxygen living resource threshold (3 mg/L) between 9.6 and 18.8% of the time during the summer months between 2007 and 2013. DO concentrations fell below the threatened threshold (5 mg/L) between 31 and 48% of the time.

Table 4.3.4 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring site in Assawoman Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
XDN6921 Grey's Creek	**DO<5**	NS	31.5%	43.1%	43.9%	44.9%	33.7%	48.1%
	DO<3	NS	9.6%	18.4%	17.8%	18.0%	8.6%	18.8%

National Coastal Condition Assessment status: During the 2010 NCCA, all stations in Assawoman Bay were sampled mid-day, when oxygen values are expected to reach their highest. Yet, all stations failed the diurnal minimum living resources threshold (5 mg/L), even at depths of 1 m or less (NCA06-0036, XDN7545).

Table 4.3.5 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in Assawoman Bay

Station	Date	Time	Depth (m)	Bottom DO
XDN7545	2-Aug	11:13	1.0	3.47
NCA06-0036	2-Aug	13:06	0.7	4.32
XDN5737	2-Aug	14:00	1.5	4.49
NCCA10-1618	2-Aug	14:47	1.3	4.83

Total Maximum Daily Load Status: The TMDL analysis of the growing season all sites except one failed the threshold >5% of the time. When just the summer months were analyzed this increased significantly (31-47%) (Table 4.3.21).

St. Martin River

Fixed Station Status: All stations were borderline or failed the living resources threshold (5 mg/L) during all analysis periods. No station passed this threshold during the two most recent analysis periods.

Table 4.3.6 Rolling three year results for the 98th percentile of dissolved oxygen (mg/L) in St. Martin River (June- September).

Area	STATION	07-09	08-10	09-11	10-12	11-13
Bishopville Prong	BNT0012	4.3	4.3	3.1	3.1	3.1
	BSH0030	0.3	0.3	0.1	0.1	0.1
	MCBP 11			3.1	2.7	2.7
	XDM4486	1.8	2.6	0.1	0.1	0.1
	BSH0008	2.4	3.0	1.2	1.2	1.2
Spring Branch	MXE0011	4.2	4.2	4.0	4.0	4.0
	BIH0009	4.7	4.9	4.7	4.7	4.7
	MCBP 25			5.0	4.5	4.5
	SPR0009*	0.5	0.5	0.5	2.0	2.0
	SPR0002	2.1	2.1	2.1	2.1	1.6
St. Martin River	MCBP 13			4.8	4.8	0.1
	XDM4797*	2.7	2.7	2.7	2.9	1.0
	MCBP 22		5.4	3.7	3.7	3.7
	MCBP 3		5.4	3.5	3.5	3.5
	XDN4312	3.8	3.8	3.3	3.3	2.3
	XDN3724*	3.2	4.0	4.0	4.5	4.5

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring Status: Over the 7-year period, the continuous monitoring station on Bishopville Prong failed the living resources diurnal DO threshold (5 mg/L) between 39 and 56% of the time (2008 and 2011, respectively). Failure relative to the minimum threshold of 3 mg/L ranged from 15 to 27% of the time, (2008 and 2013, respectively). There is no pattern of improvement or deterioration in oxygen conditions measured by continuous monitoring.

Table 4.3.7 Annual **s**ummer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring site in the St. Martin River

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
XDM4486 Bishopville Prong	**DO<5**	48.9%	39.6%	50.5%	40.7%	55.8%	43.8%	49.2%
	DO<3	24.7%	15.0%	24.6%	16.1%	26.4%	18.2%	27.3%

National Coastal Condition Assessment status: In contrast to the picture painted by the 3-year status values, one-time measurements of summer DO at three stations during 2010 all passed the living resources threshold of 5 mg/L. Such distinct differences demonstrate the risk of using single samples to characterize a parameter that is highly variable on daily and seasonally temporal scales. At St. Martin River stations, DO attainment as measured by NCCA is completely reversed compared to 3-year status, with the upstream stations appearing to be in better condition than the station at the river mouth, which is a misleading depiction of DO. Continuous monitoring data available for that date and time shows a DO of 8.44 mg/L (130% saturation). The entire daily range, however shows DO declining below 5 mg/L at 04:45 (4.98 mg/L) with a minimum of 3.76 mg/L (55.3% saturation) at 07:30. Oxygen concentrations remained below 5 mg/L until 10:00, for a total of 5.25 hours.

Table 4.3.8 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in the St. Martin River.

Area	Station	Date	Time	Depth (m)	Bottom DO
Spring Branch	SPR0009	4-Aug	13:00	0.8	6.36
St. Martin River	XDM4797	4-Aug	13:30	1.0	7.52
	XDN3724	4-Aug	12:27	1.5	5.03

Total Maximum Daily Load Status: The TMDL analysis of the growing season revealed all of the sites in the St Martin River failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed this increased significantly (30-66%) (Table 4.3.21).

Isle of Wight Bay

Fixed Station Status: The open bay sites closest to Ocean City Inlet (XDN0146, XDN2438) consistently achieved the living resources threshold (5 mg/L), probably due to the influence of cool, oxygenated ocean water. Two additional open bay sites (XDN2340, MCBP34) also achieved this threshold during most analysis periods. All tributary stations consistently failed the threshold of 5 mg/L, and MCBP16, MKL0010, MCBP30, and MCBP6 also consistently failed the minimum dissolved oxygen threshold of 3 mg/L. MKL0010 is a deep station, which has a negative effect on oxygen compared to shallower stations.

Table 4.3.9 Rolling three year results of the 98th percentile of dissolved oxygen (mg/L) in Isle of Wight Bay (June- September) compared to the percent failure of the Total Maximum Daily Load standard of 5mg/L (June- August) during 2011-2013.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Manklin Creek	MCBP 16		2.3	1.9	1.9	1.9
	MKL0010*	0.1	0.1	**0.1**	**0.1**	**0.1**
	MCBP 9		3.4	3.1	0.9	0.9
Turville Creek	MCBP 34		5.9	5.9	5.9	
	TUV0034*	4.4	**4.4**	3.7	3.4	3.4
	MCBP 30			2.8	2.8	2.8
	TUV0019	4.0	4.0	4.0	4.1	4.3
	TUV0011	**4.6**	4.6	4.6	3.5	3.5
Herring Creek	HEC0012*	4.4	4.4	3.7	3.7	3.7
	MCBP 6			2.7	2.6	1
Isle of Wight Bay	XDN3445	4.6	4.6	4.6	5.3	3.4
	XDN2340	4.3	5.0	5.0	5.3	5.3
	MCBP 5			3.7	3.7	3.7
	XDN2438	5.8	6.0	5.6	5.6	5.6
	XDN0146	5.3	5.3	6.1	5.1	5.1

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: A continuous monitor was deployed in this segment, in Turville Creek, only during 2007. The 5 and 3 mg/L criteria were not met 42% and 13% of the time (Table 4.3.10).

Table 4.3.10 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring sites in Isle of Wight Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
TUV0021 Turville Creek	**DO<5**	42.4%	NS	NS	NS	NS	NS	NS
	DO<3	13.1%	NS	NS	NS	NS	NS	NS

NS – not sampled

National Coastal Condition Assessment status: Instantaneous DO measurements collected during 2010 again show very different results from full-season and continuous monitoring. Upstream and open bay sites appear little different from one-another, with the site closest to Ocean City Inlet (NCA06-0045) exceeding the living resources diurnal threshold (5 mg/L), showing the mitigating influence of the ocean on DO. In contrast, 3-year 98th percentiles show that upstream sites consistently fail one or both thresholds. This one time assessment does not reveal the same low oxygen problem that is shown by more routine monitoring (Table 4.3.9).

Table 4.3.11 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, assessment in Isle of Wight Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Manklin Creek	MKL0010	4-Aug	11:41	0.8	5.58
Turville Creek	TUV0034	4-Aug	18:15	2.5	4.34
Herring Creek	HEC0012	4-Aug	10:27	0.5	4.05
Isle of Wight Bay	NCCA10-1614	3-Aug	8:01	1.3	4.63
	NCCA10-1614	7-Sep	12:30	1.6	5.55
	NCCA10-1622	2-Aug	17:26	1.0	4.20
	NCA06-0045	4-Aug	8:50	2.7	6.17

TMDL Status: The total maximum daily load analysis of the growing season results showed half of the sites in Isle of Wight Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (17-74%) (Table 4.3.21).

Sinepuxent Bay

Fixed Station Status: Until the 2010-12 analysis period, no site met the living resources threshold of >5 mg/L. Four sites never met it during any analysis period. All but one site (MCBP10 – South Point Landing) did meet the instantaneous minimum threshold of threemg/l (Figure 4.3.3 and Table 4.3.12). Improvements have occurred at sites well within the bay (ASIS 2, ASIS17, ASIS18), but the continued failure of ASIS 1, close to Ocean City Inlet and XDN0146, is puzzling.

Table 4.3.12 Rolling three-year assessment of summer (June – Sept) dissolved oxygen (mg/L) in Sinepuxent Bay (98th percentile).

STATION	07-09	08-10	09-11	10-12	11-13
ASIS 16	4.6	4.6	4.6	4.1	4.0
MCBP 10	0.3	0.3	0.3	1.5	1.5
ASIS 2*	5.0	4.6	4.6	4.6	5.3
MCBP 31		4.1	3.6	3.6	3.6
ASIS 18	4.8	4.8	4.8	5.4	5.5
ASIS 17	4.9	4.9	4.9	5.0	**5.7**
ASIS 1	4.8	4.4	4.4	4.2	4.2

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring Status: ASIS maintains a continuous monitor at a tide gauge station near the Verrazano Narrows Bridge. Data available from 2009-13 shows that the site failed the 3 mg/L criterion less than 10% of the time in all years except 2010, when it failed 12.6% of the time (Table 4.3.13). Failure at the 5 mg/L criterion was more frequent, about 43% in 2009-10, but improved markedly in 2011-12 with failure between 24 and 28% time (Table 4.3.13). Encouragingly, in 2013 failure improved to only 5.2% of the time.

Table 4.3.13 Annual summer (June-September) dissolved oxygen threshold (either 3 or 5 mg/L) percent failure at continuous monitoring sites in Sinepuxent Bay (ASIS Tide Station 1 near the Verrazano Bridge).

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
ASIS TS1	DO<5	NS	NS	43.6%	43.7%	28.0%	24.3%	5.2%
	DO<3	NS	NS	6.2%	12.6%	4.9%	0.2%	0.02%

NS – not sampled

National Coastal Condition Assessment status: At station ASIS 2, the instantaneous DO measured during 2010 was well above the living resources threshold of 5 mg/L, but again, the measurement was collected during the mid-afternoon when DO concentrations are expected to be at a high point on the diurnal cycle. This was better oxygen value compared to the fixed station three year analyses (Table 4.3.12) showing a single data point may not capture low oxygen in non-stratified systems.

Table 4.3.14 2010 National Coastal Condition Assessment instantaneous dissolved oxygen in Sinepuxent Bay.

Station	Date	Time	Depth (m)	Mean DO
ASIS-2	4-Aug	16:00	1.8	6.94

Total Maximum Daily Load Status: The TMDL analysis of the growing season dissolved oxygen revealed two out of five sites in Sinepuxent Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (13-15%) (Table 4.3.21).

Newport Bay

Fixed Station Status: With the exception of Beaverdam Creek (BMC0011) and the mouth of Newport Creek (A3), all sites consistently failed the > 5 mg/L threshold (Table 4.3.15).

Marshall Creek (MSL0011), the head of Trappe Creek (MCBP 23), and the mouth of Newport Creek (MCBP 15) failed the instantaneous minimum of 3 mg/L threshold. Marshall Creek is one of the deepest stations sampled and stratifies. The station at the mouth of Newport Creek is within a marsh embayment that may receive poor exchange with the mainstem creek.

The Ayers Creek sites are co-located. During the most recent 3-year analysis periods, both sets of measurements consistently failed the instantaneous minimum of 3 mg/L threshold (Figure 4.3.3).

Table 4.3.15 Three-year 98-percentile of dissolved oxygen (mg/L) in Newport Bay.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Trappe Creek	KIT0015	2.9	2.9	3.8	3.8	4.4
	BOB0001	1.5	4.5	4.3	4.3	4.3
	MCBP 4			5.1	2.8	2.5
	MCBP 23	0.9	0.9	0.9	1.7	1.5
	TRC0059	2.4	3.1	4.4	4.1	4.1
	MCBP 35	1.4	3.0	3.4	3.4	3.4
	TRC0043	3.1	4.0	4.0	4.0	4.8
Ayers Creek	AYR0017	3.8	3.9	3.9	2.7	2.7
	MCBP 33	2.1	2.1	1.7	1.7	1.5
Newport Creek	BMC0011	**6.4**	6.3	6.3	5.9	5.9
	NPC0031	3.1	3.6	3.0	3.0	3.0
	NPC0012*	3.6	3.6	3.6	4.7	4.8
	ASIS 4	4.8	4.7	4.6	4.6	4.6
	MCBP 15	0.1	0.5	0.5	1.1	1.2
Newport Bay	XCM4878*	3.8	3.8	3.9	3.9	4.6
	ASIS 3	4.7	4.8	4.8	5.0	5.0
Bassett Creek	MCBP 28	4.6	4.6	1.2	1.2	1.2
Marshall Creek	MSL0011	1.8	1.8	1.8	2.4	2.4
	MCBP 12	0.9	0.9	0.1	0.1	0.1

bold values are significantly different from boundary values.
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: Data available from the continuous monitor at Newport Creek (2007-2013) shows that the site failed the 3mg/L criterion less than 10% of the time in all years except 2011 (Table 4.3.16) Failure at the 5 mg/L criterion was more frequent, varied between 21-42% with the lowest failure rate in 2013.

Table 4.3.16 Percent failure of summer (June-September) dissolved oxygen, DO, thresholds in Newport Creek (2007-2013).

Area	Station	Threshold	2007	2008	2009	2010	2011	2012	2013
Newport Creek	NPC0012	DO<5	42.2%	30.6%	38.8%	39.3%	41.8%	28.7%	21.3%
		DO<3	11.1%	4.5%	7.3%	7.8%	10.2%	2.6%	0.5%

National Coastal Condition Assessment status: The sampling in 2010 occurred at only two stations in Newport Bay. Rolling 3-year status analyses show both of these stations consistently failing the living resources threshold (5 mg/L) during all analysis periods, but the single event samples collected for NCCA show DO exceeding the highest threshold (>7 mg/L) (Table 4.3.17). These data provide strong evidence that instantaneous measurements of oxygen do not provide accurate measures of ecosystem condition.

Table 4.3.17 2010 NCCA instantaneous dissolved oxygen, DO, in Newport Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Newport Creek	NPC0012	5-Aug	16:45	0.4	10.45
Newport Bay	XCM4878	3-Aug	13:15	1.6	7.05

Total Maximum Daily Load Status: The TMDL analysis of the growing season demonstrated three quarters of the sites in Newport Bay failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (13-55%) (Table 4.3.21).

Chincoteague Bay

Fixed Station Status: Open bay sites tended to meet the living resources (5 mg/L) and instantaneous minimum (3 mg/L) thresholds. All nearshore stations except MCBP18 failed the living resources threshold (Table 4.3.18). The single tributary station (MCBP29), located at the dam on Big Mill Pond, failed all thresholds, and showed that Big Mill Pond was a source of poorly oxygenated water to Swan Gut.

Table 4.3.18 Three-year 98th percentile of dissolved oxygen (mg/L) in Chincoteague Bay.

Area	STATION	07-09	08-10	09-11	10-12	11-13
Maryland	XCM1562	5.0	4.7	4.7	4.7	5.3
	XCM0159*	5.2	4.7	4.7	4.7	5.4
	ASIS 5	4.2	4.2	4.2	4.5	4.5
	XBM5932	5.5	5.6	5.6	5.6	**5.5**
	MCBP 18			5.3	5.2	5.2
	ASIS 6	4.2	4.2	4.2	4.6	4.9
	XBM8149	5.4	4.6	4.6	4.6	5.4
	MCBP 24			3.8	3.8	3.8
	ASIS 7*	4.6	4.0	3.8	3.8	3.8
	ASIS 14	4.8	4.7	4.7	4.7	4.9
	XBM3418	5.4	5.4	5.2	5.2	5.2
	ASIS 15	5.0	4.4	4.4	4.4	4.5
	MCBP 27			3.7	3.7	3.7
	XBM1301*	5.4	5.3	5.0	5.0	4.8
	MCBP 29		0.9	0.9	0.9	
Virginia	ASIS 9	4.1	4.6	4.6	4.7	4.8
	ASIS 10*	4.7	3.5	3.5	3.5	4.7
	ASIS 8	4.2	4.2	4.2	4.2	**4.5**
	ASIS 11	4.9	4.6	4.6	4.6	4.8
	ASIS 12	3.7	3.5	3.5	3.5	4.8
	ASIS 13	4.8	5.4	4.7	4.7	4.5

bold values are significantly different from boundary values in all tables
grey cells have insufficient data for analysis
blank cells have no data for that timeframe
* sampled during 2010 NCCA

Continuous monitoring status: The continuous monitoring station at Tingles Island was active only during the last five years of the report period. Dissolved oxygen failed the living resources threshold (5 mg/L) between 1.3 and 45.4% of the time (Table 4.3.19). On a positive note, the failure rate has declined annually through the entire period. Similarly, the failure rate for the instantaneous minimum threshold declined over the entire period, from 9.2% of the time to 0.1%. Public Landing failed the living resources DO threshold (5 mg/L) between 9.2 and 18.6% of the time (2009 and 2011, respectively) (Table 4.3.19). Failure relative to the minimum threshold of 3 mg/L ranged from 0.1 to 1.2% of the time, (2012 and 2010, respectively).

Table 4.3.19 Annual summer (June-September) dissolved oxygen, DO, threshold percent failure at continuous monitoring stations in Chincoteague Bay

Station	Threshold	2007	2008	2009	2010	2011	2012	2013
ASIS TG2 Tingles Island	DO<5	NS	NS	45.4%	31.2%	30.1%	11.5%	1.3%
	DO<3	NS	NS	9.2%	8.7%	1.8%	0.6%	0.1%
XBM8828 Public Landing	DO<5	14.5 %	18.4%	9.2%	15.9%	18.6%	16.4%	10.9%
	DO<3	0.3%	0.6%	0.7%	1.2%	0.4%	0.1%	0.6%

NS – not sampled

National Coastal Condition Assessment status: NCCA sampling in 2010 occurred at 9 stations in Chincoteague Bay. All stations met the living resources threshold (5 mg/L) for these single time samples, and three (NCA06-0041, XCM0159, ASIS10) exceeded the seagrass objective (Table 4.3.20). This is consistent with the conmon data, which show that meeting or exceeding the threshold is more likely than failure in Chincoteague Bay. These data provide strong evidence that instantaneous measurements of oxygen do not provide accurate measures of ecosystem condition.

Table 4.3.20 National Coastal Condition Assessment (2010) instantaneous dissolved oxygen, DO, in Chincoteague Bay

Area	Station	Date	Time	Depth (m)	Mean DO
Maryland	NCA06-0039	3-Aug	14:11	1.7	6.60
	XCM0159	3-Aug	18:20	2.0	7.36
	NCA06-0041	3-Aug	15:09	2.0	7.35
	NCCA10-1633	3-Aug	16:35	1.3	6.50
	ASIS 7	5-Aug	11:29	0.9	6.10
	NCA06-0033	5-Aug	10:44	1.6	6.18
	NCCA10-1629	5-Aug	12:27	1.0	6.46
	XBM1301	5-Aug	9:30	1.8	6.10
Virginia	ASIS 10	5-Aug	14:04	1.0	7.13

Total Maximum Daily Load Status: The TMDL analysis of the growing season approximately half of the sites failed the 5 mg/L threshold >5% of the time. When just the summer months were analyzed the percent samples failing increased significantly (9-31%) (Table 4.3.21).

Table 4.3.21 Total Maximum Daily Load, TMDL, analysis- 2001-2004 vs 2011-2013 water quality monitoring data indicating the percent of time dissolved oxygen levels are not meeting the TMDL endpoint of 5 mg/L (all oxygen readings from profile data used). Red box indicates greater failure rate in more recent period (2011-2013) compared with TMDL analysis (2001-2004).

Sub-basin	Station Name	Growing season (May-Oct) % > Threshold		Summer (June-August) % > Threshold	
		2001-2004	**2011-2013**	2001-2004	**2011-2013**
Assawoman Bay	GET0005	16.7	**17.6**	16.7	47.6
	XDN4851	6	**5.6**	9.1	11.1
	XDN5737	32.1	**3.3**	23.5	5.8
	XDN6454	8.8	**17**	14.7	33.3
	XDN7261	26.2	**16.2**	19.2	31.3
	XDN7545	36.9	**20.4**	39.3	40.7
St. Martin River	BSH0008	44.2	**35.5**	57.1	**56.1**
	BSH0030	25	**38.9**	25	**66.7**
	SPR0002	12.2	**32.5**	16.7	**55**
	SPR0009	25	**22.2**	39.1	**35.7**
	XDM4486	42.1	**50**	47.1	**68**
	XDM4797	27.7	**27**	39.1	**39.1**
	XDN3724	13.2	**13.9**	22.2	**29.8**
	XDN4312	35	**19.6**	51.7	**38.8**
Isle of Wight Bay	TUV0011	45.9	**7.5**	45.5	**16.8**
	TUV0019	25	**16.7**	41.7	**22.2**
	TUV0034	17.4	**44.4**	18.4	**46**
	MKL0010	65.5	**48.1**	74.3	**74.4**
	XDN0146	0	**0**		**0**
	XDN2340	1.4	**0**		**0**
	XDN2438	0	**0**		**0**
	XDN3445	29.5	**0.9**	25	**1.9**
Newport Bay	AYR0017	8.3	**11.1**	16.7	**25.4**
	BMC0011	0	**0**	?	**0**
	BOB0001	8.3	**16.7**	8.3	**20.6**
	KIT0015	4.2	**12.5**	8.3	**25**
	MSL0011	54.2	**38.9**	75	**55.6**
	NPC0012	41.7	**11.1**	58.3	**12.7**
	NPC0031	29.2	**27.8**	25	**31.7**
	TRC0043	4.3	**5.6**	9.1	**12.7**
	TRC0059	25	**16.7**	25	**20.6**
	XCM4878	10.3	**2.8**	13	**5.6**
	ASIS 3	4.4	**1.4**	5.6	**0**
	ASIS 4	10.8	**18.2**	18.8	**12.7**
Sinepuxent Bay	ASIS 1	8.9	**8.2**	15	**13.1**
	ASIS 2	0	**0**	0	**0**
	ASIS 16	2	**14.4**	5	**15.6**
	ASIS 17	0	**0**	0	**0**
	ASIS 18	0	**0**	0	**0**
Chincoteague Bay, MD	XBM1301	1.4	**5.6**	2.7	**11.1**
	XBM3418	4.3	**0**	8.3	**0**
	XBM5932	0	**0**		**0**
	XBM8149	8.7	**0**	16.7	**0**
	XCM0159	6.5	**0**	12.5	**0**
	XCM1562	5.9	**0**	11.1	**0**
Chincoteague Bay, VA	ASIS 5	0	**18.2**	0	**26.5**
	ASIS 6	0	**4**	0	**0**
	ASIS 7	17.1	**20.4**	35.7	**31.2**

	ASIS 8	10.5	**16.7**	25	**21.3**
	9	8.9	**10.5**	22.2	**9.7**
	10	2.4	**15.5**	5.9	**11.1**
	11	1.6	**4.6**	4.5	**8.7**
	12	0	**5**	0	**9.8**
	13	5.1	**6.6**	4	**10.4**
	ASIS 14	9.3	**1.4**	22.2	**0**
	ASIS 15	9.6	**5.6**	23.8	**12.7**

Summary

Although the Coastal Bays are shallow lagoons, which typically do not stratify, low oxygen values were frequently found in some areas. Daytime measurements show that DO falls below 5 mg/L during the summer months throughout bays and their tributaries, with the exceptions mainly at open bay sites. Areas that have <5 mg/L dissolved oxygen during the day likely provide extremely stressful habitat at night, when respiration in the absence of photosynthesis synergistically reduces oxygen values even further.

Dissolved oxygen indicators can be problematic in an unstratified, shallow system especially when relying primarily on daytime measurements (which can be highly variable). Diel data showed that DO is frequently less than the 5 mg/L threshold in the tributaries (40 – 60% of the time in Turville Creek and Bishopville Prong). Possible causes of observed low DO values include respiration of large algae blooms (responding to high nutrient availability); bloom decay; high sediment oxygen demand from organically enriched sediments in many areas (Wells and Conkwright 1999; UMCES 2004); decay of macroalgae, seagrasses, and/or marsh vegetation; and poor circulation.

As demonstrated by the use of continuous monitoring data, when sampling frequency and spatial coverage increases, the understanding of oxygen conditions in the Coastal Bays improves. Even where only daytime measurements of DO are practical, increasing frequency and examining seasonal differences provides a more robust insight into dissolved oxygen. This is evident by comparing one-time samples collected during late summer for National Coastal Condition Assessment once every five years, to 3-year medians collected during all four summer months (increasing frequency). NCCA samples show that DO concentrations can meet or exceed thresholds, and appear to represent adequate or good conditions, while more frequent sampling, demonstrates that oxygen fails criteria at a majority of sampling sites within the Coastal Bays.

When comparing continuous monitoring data to the spatially more robust fixed monthly station data, the continuous monitoring data provides a more nuanced picture of dissolved oxygen conditions. Continuous monitoring ites overlap fixed sites at two locations, XDM4486 in St. Martin River and TS1/A2 in Sinepuxent Bay, allowing direct comparison. In St. Martin River, continuous monitoring data show that the minimum threshold (3 mg/L) failure occurs only 15-27% of the time at a specific site, while spatially more robust monthly sampling indicates that on a system-wide basis DO fails the minimum threshold during all analysis periods. In Sinepuxent Bay the continuous monitoring data shows minimum threshold (3 mg/L) failure between 0.02% and 12.6%. The living resources threshold was not met between 5.2% and 43.7% of the time. The failure rate declined annually for both thresholds. The fixed station shows improvement and met the living resources threshold during the last analysis period (2011-13), but failed this threshold during all other periods. Similar results are shown in comparisons among continuous monitor and monthly measurements in Assawoman Bay, where the continuous monitoring site is within 0.75 Km of a fixed site (XDN6921, GET0005 respectively). Here, continuous monitoring data show that the minimum threshold (3 mg/L) failure occurs only 10-19% of the time, while monthly sampling indicated that the fixed site DO fails the minimum threshold during all but the most recent analysis period. During 2011-13 the fixed site failed the living resources threshold (5 mg/L), while the continuous monitoring showed failure between 34-48% of the time during those years. Where conditions are typically good, analyses of fixed station data based on the 98th percentile will find those DO values that do fail the thresholds, and may paint a much poorer picture than the conditions that actually exist.

Next Steps

During 2012, a study was undertaken to begin development of a time-of-day calibration model for Coastal Bays long term fixed monthly monitoring stations in order to adjust DO to a fixed and comparable time of day so that spatial patterns and long term trends may be more accurately assessed. Typically, oxygen levels are assessed against a criterion with a failure allowance to account for natural variability. The criterion is set at 5.0 mg/L and the failure rate is computed for observed DO for a sequence of times of day. As expected, the frequency of falling below 5.0 tends to decrease with increasing time of day for observed DO. It is clear that observations taken during mid and late day do not reflect the stress that is experienced due to low DO in the water column in the early morning.

Continuous monitoring technologies implemented over the last decade provide high frequency datasets (observations every 15 minutes) that reveal new insights on short temporal DO patterns, including diel cycles. Typical diel patterns in the Coastal Bays reveal that the lowest DO and greatest stress to aquatic fauna occurs in the early morning. As the DO producing chlorophyll of phytoplankton are activated by sunlight, DO concentrations rise through the day to reach a zenith in mid or late afternoon. As sunlight wanes and respiration continues, DO decreases to a minimum in the early morning of the following day when the cycle begins again. On observing this cycle, it becomes apparent that it is difficult to discern spatial patterns of DO in the fixed station data because observations at different stations are taken at different times. Thus the difference in DO between two station observations is partly due to change in location and partly due to the progression of DO in its diel cycle.

This study attempted to model the diel cycle of DO as a function of numerous variables to obtain estimates of the diel cycle that could be used to adjust DO observations taken at any time of day to reflect the DO at a time of day associated the greatest DO stress. The results are mixed, which indicates that improvement is needed before the method can be generally applied. The evidence of bias that emerged from the validation study indicates that the true diel cycle has systematic departures from the trigonometric model that was employed. Thus one avenue for improvement might be to replace the trigonometric model with something like a spline function that would have greater flexibility in attempting to mimic the diel cycle. Another approach that might be explored would use day-specific diel trends to make the diel adjustment, rather than a diel-cycle predicted based on day specific attributes such as photosynthetically active radiation (PAR), temperature, turbidity, and chlorophyll. That is, a smoothing model applied to the diel trend observed at a Con-Mon site contemporaneous to the fixed station observations could be used to make the diel adjustment. A third area of improvement might be to explore a modeling approach that would identify days with a very weak diel cycle. Weak diel cycles may be related to phytoplankton bloom changes, such as succession or termination. In this study weak diel cycle days were essentially excluded by removing all days where the diel cycle model had r-square less than 0.7. It is likely that some of the poor performance is due to applying a diel cycle model to days where diel cycle is weak.

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Chapter 4.4

Integrated Water Quality Index in the Maryland Coastal Bays

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Abstract
The Water Quality Index synthesizes the status of the four water quality indicators; chlorophyll *a* (algae: Chl *a*), total nitrogen (TN), total phosphorus (TP), and dissolved oxygen (DO) into a single indicator of water quality. This indicator is similar to the Dow Jones Index, which compiles information on multiple stocks and provides a simple number to track over time. The Water Quality Index compares measured variables to values known to maintain fisheries (DO) and submerged aquatic grasses (Chl *a*, TN, and TP). The Index joins these together into one number between zero and one. During the most recent index period of 2011-2013, the chlorophyll threshold was most often achieved while thresholds for dissolved oxygen and total phosphorus were least met. Currently, Assawoman Bay, the St. Martin River, Isle of Wight tributaries and Newport Bay show degraded water quality largely due to high nutrient inputs, while the open bays have fair to excellent water quality.

Introduction
The Water Quality Index (WQI) was designed to synthesize the status of chlorophyll *a*, total nitrogen, total phosphorus, and dissolved oxygen into a single parameter. Three year median values of these variables (see previous water quality chapters) are compared to criteria based on ecosystem function, such as maintaining fisheries (DO threshold) and maintaining submerged aquatic grasses (Chl *a*, TN, and TP threshold). The Index is unitless and is scaled between zero and one, such that a WQI of one indicates habitat suitable for fish and aquatic grass survival, while a value of zero indicates relatively unsuitable habitat for either fish or aquatic grasses. Intermediate values indicate a system in flux, where it might be expected that some ecosystem functions (grass beds or fish) may be present some of the time. This approach of summarizing compliance of water quality variables with threshold values has previously been carried out to compare US mid-Atlantic estuaries as well as tributaries within the Chesapeake Bay (Kiddon *et al*, 2003; Jones *et al*, 2003).

Management Objective: Maintain suitable fisheries and seagrass habitat.

Draft Indicator: Water quality Index >0.6

Data Analyses
For the 60 sampling sites with at least 10 records for all variables between 2011 and 2013, median values for each variable were calculated. Median values were then

compared to established threshold values (Table 4.4.1) and scored as one (meets criteria) or zero (fails to meet criteria). These scores were summed for all four variables and divided by the number of variables to result in an index value ranging from zero to one for each sampling location. An index value of zero indicated that a site met none of the habitat suitability criteria, while a score of one indicated a site that met all habitat suitability criteria. Once an index value had been calculated for each site, the index value for all sites within several reporting regions were averaged and these values are presented by measured variable (Table 4.4.1) and combined regional index values (Table 4.4.3). Standard error associated with mean index values in these cases represents spatial variation between sites, within a reporting region, and does not include temporal variability.

Table 4.4.1 Variables and threshold values used in the calculation of the Water Quality index for Maryland Coastal Bays (1: Dennison *et al*, 1993; 2: Orth *et al.* 2002; 3: Chesapeake 2000, 4: Stevenson *et al*, 1993).

Variable	Threshold value	Reference
WQI		
Chl a	< 15 µg L^{-1}	1, 2
Total nitrogen	< 0.65 mg L^{-1} (46 µM)	4
Total phosphorus	< 0.037 mg L^{-1} (1.2 µM)	4
Dissolved oxygen	> 5 mg L^{-1}	3

Results

<u>Status of the Water Quality Index</u>

Water quality index values in upstream stations that show a better rating than downstream were due to lower chlorophyll values in these areas (above chlorophyll maximum for stream, not really improved water quality in these areas).

Assawoman Bay

None of the sites within Assawoman Bay met the WQI indictor threshold. Four sites were degraded and two sites had fair water quality conditions (Figure 4.4.1). This is largely due to high nutrient inputs (almost all sites failed TN or TP thresholds) and poor oxygen (no sites passed) (Table 4.4.2) since all sites passed chlorophyll thresholds.

St. Martin River

All sites failed TN, TP, and DO thresholds suggesting that high nutrient loading to these regions is reducing water quality. Six sites in St. Martin River had very degraded water quality category (no indicators met threshold values), while the other five stations were destermined to have degraded water quality (typically these sites passed the chlorophyll threshold) (Figure 4.4.1). Broader impacts of these nutrients are becoming evident in this region, with over half the sites failing chlorophyll (Table 4.4.2). There was slightly better water quality upstream due to naturally lower chlorophyll values upstream (Table 4.4.2).

Isle of Wight

Within the Isle of Wight region, a clear distinction occurred between open bay and tributary sites. Three of the four open bay sites had good water quality (only failed the TP threshold); the five tributary sites had degraded water quality conditions (Figure 4.4.1). All sites in Isle of Wight watershed passed the chlorophyll threshold yet failed the TP threshold. The three open bay sites passed the TN threshold; however, all tributary sites exceeded the TN threshold (Table 4.4.2). The station at the Ocean City Inlet was rated as fair because it failed both the TN and DO thresholds. Overall, Isle of Wight had fair conditions.

Sinepuxent

Overall, Sinepuxent Bay had good water quality (Figure 4.4.1). All stations passed the thresholds for chlorophyll, DO, and TN. The slightly reduced water quality in the north resulted from failure to meet the TP threshold at three sites (Table 4.4.2, Figure 4.4.1).

Newport

Most sites in Newport Bay tributaries were degraded or very degraded. Open bay sites had fair to good water quality (Figure 4.4.1). Only the southern bay sites passed TN or TP thresholds and half of all sites failed the chlorophyll threshold (Table 4.4.2). Upper tributary sites categorized as poor, instead of degraded, generally due to chlorophyll and/or oxygen meeting criteria (chlorophyll not always applicable and DO may be supersaturated in headwaters).

Chincoteague

Overall, Chincoteague Bay had fair conditions, yet a few mainstream sites in northern Chincoteague Bay had good water quality (Figure 4.4.1). All sites in Chincoteague Bay met the chlorophyll threshold. In the northern part of Chincoteague, most sites failed TP thresholds but nearly all sites in the southern region of Chincoteague also failed to meet the TP and DO thresholds (Table 4.4.2).

Table 4.4.2 Breakdown of WQI variables by region (mean$_{(se)}$), 2011-2013.

Bay Segment	Chl	TN	TP	DO
Assawoman	$1.00_{(0.00)}$	$0.17_{(0.17)}$	$0.17_{(0.17)}$	$0_{(0.00)}$
St. Martin	$0.45_{(0.16)}$	$0_{(0.00)}$	$0_{(0.00)}$	$0_{(0.00)}$
Isle of Wight	$1.00_{(0.00)}$	$0.44_{(0.16)}$	$0_{(0.00)}$	$0.33_{(0.15)}$
Sinepuxent	$1.00_{(0.00)}$	$1.00_{(0.00)}$	$0.20_{(0.20)}$	$0.6_{(0.24)}$
Newport	$0.58_{(0.15)}$	$0.17_{(0.11)}$	$0.08_{(0.08)}$	$0.25_{(013)}$
North Chincoteague	$1.00_{(0.00)}$	$0.67_{(0.21)}$	$0.17_{(0.17)}$	$0.67_{(0.21)}$
South Chincoteague	$1.00_{(0.00)}$	$1.00_{(0.00)}$	$0_{(0.00)}$	$0.09_{(0.00)}$

Note: (0: all sites failed to meet threshold, 1: all sites met threshold)

Summary

Overall, the Coastal Bays show generally poor or degraded water quality in or close to tributaries and good or excellent water quality in well-flushed open bay regions. Sinepuxent and north Chincoteague had good water quality, Isle of Wight poor conditions, while Assawoman Bay, St Martin River, Newport Bay and southern Chincoteague exhibited degraded water quality (Table 4.4.3, Figure 4.4.2). Variations in water quality between regions reflects variation in nutrient concentrations, however many sites throughout the system display effects of eutrophication (especially high nutrients and reduced dissolved oxygen). This has implications for aquatic communities, suggesting that many regions within the Coastal Bays do not provide suitable habitat for submerged grasses and/or fish.

Table 4.4.3 Summary of Water Quality Index , WQI,by Region. Comparison of 2001-2003 WQI results to 2011 -2013.

Region	n (sites)	WQI (se) 01-03	Health	WQI 11-13	
Assawoman	6	**0.33** (0.05)	Degraded	**0.33** (0.05)	**Degraded**
St Martin	11	**0.33** (0.05)	Degraded	**0.11** (0.04)	**Very degraded**
Isle of Wight	9	**0.53** (0.07)	Poor	**0.44** (0.08)	**Poor**
Sinepuxent	5	**0.85** (0.06)	Excellent	**0.70** (0.05)	**Good**
Newport	12	**0.39** (0.08)	Degraded	**0.27**(0.08)	**Degraded**
North Chincoteague	6	**0.63** (0.09)	Good	**0.63** (0.03)	**Good**
South Chincoteague	11	**0.82** (0.04)	Excellent	**0.52** (0.02)	**Degraded**

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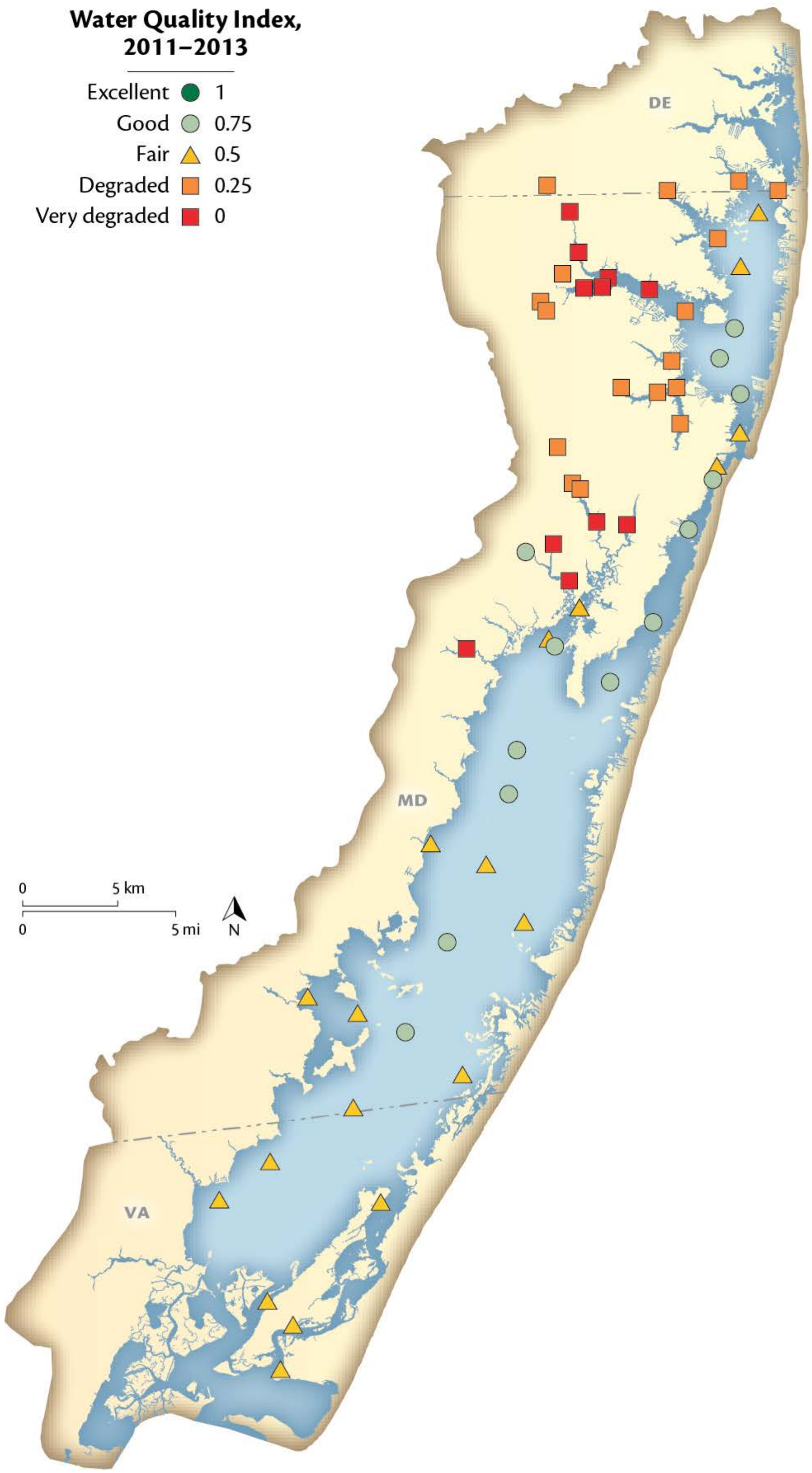

Figure 4.4.1 Water Quality Index values, 2011-2013, for all fixed sampling stations based on amalgamated median indicator values.

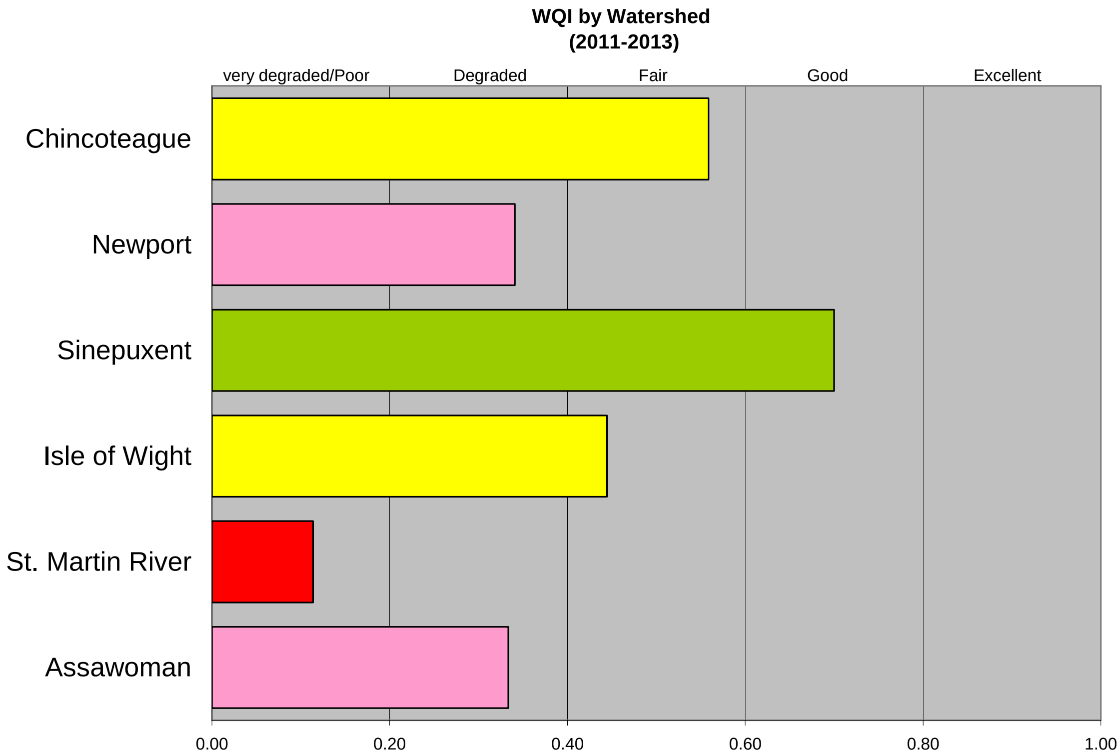

Figure 4.4.2 Overall Water Quality Index values for each of the Coastal Bays.

Chapter 4.5

Benthic Microalgae in the Maryland Coastal Bays

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Abstract
Benthic microalgae was measured as part of the National Coastal Assessment Program in 2010 at 25 sites (Figure 4.5.1). The results show that benthic microalgae play a significant role in the Coastal Bays and may even exceed water column plankton biomass in some areas. It is recommend that benthic microalgae sampling (biomass and community species composition) should be incorporated in monitoring and research efforts.

Introduction
Benthic microalgae, BMA, are single-celled microscopic photosynthetic organisms (primarily diatoms, dinoflagellates, and cyanobacteria) that inhabit the top 0-3 cm of the sediment surface and are sometimes referred to as microphytobenthos (MPB). Benthic chlorophyll is an indicator of the microalgal biomass on the sediment surface. This is the primary food resource available to benthic grazers such as shellfish and numerous finfish species (Lower Cape Fear River Program 2004).

The chlorophyll biomass (mg/m^2, a measure of quantity) of benthic microalgae can be important in determining the total effect of the microalgal community on the water column. BMAmay make up a large proportion of the total biomass of estuarine microscopic photosynthesizing organisms (McComb and Lukatelich 1986), have been found to be up to 17% of the total production in a European estuary (de Jong and deJonge 1995) and the most productive marine primary producers in an Australian estuary (Moreton Bay: see p164 Dennison and Abal 1999). A number of factors have been shown to influence the establishment and productivity of BMA. These include; season, irradiance, concentrations of nitrogen, phosphorus and silicon, tidal range, sediment type, and precipitation (Brotas and Catarino 1995; Carruthers 2004).

The surficial layer of sediments is a zone of intense microbial and geochemical activity and of considerable physical reworking. The vertical distribution of BMA is the net effect of the opposing actions of migration to the sediment surface by motile organisms and mixing which tends to produce a uniform distribution in the surface layer.

The variability in vertical distribution may be confounded by considerable horizontal patchiness (MacIntyre *et al*. 1996). Distributions of viable BMA have been found to extend into the mixed layer of 15 mm (MacIntyre and Cullen 1995) and more than 0.5 cm into surface sediments (de Jong and Colijn 1994). MacIntyre and Cullen (1995) reported that primary production was more or less equally distributed between the surficial millimeter of benthos and the overlying water and that vertical distributions of chlorophyll *a* in sediments, varied by up to four times over scales of 1 to 10 mm (MacIntyre and Cullen, 1995). Chlorophyll *a* concentrations in the 0-1 mm layer of sediment varied by up to 8 times on three successive days (MacIntyre and Cullen 1995; Deeley and Paling 1999).

Data Sets

Benthic chlorophyll was measured as part of the National Coastal Assessment Program in 2010 at 25 sites (Figure 4.5.1). Each site was the average of triplicate samples.

Management Objective: None

Benthic Chlorophyll Indicator: None

Data Analysis

Although the sediment may contain non-viable phytoplankton cells, which have sunk out of the water column, only those algal cells that are viable (able to grow) in the sediment have been presented here (reported as active chlorophyll).

In 2010, three replicates were collected at 25 benthic chlorophyll sites in the Coastal Bays. A small sample was taken from the top one centimeter of the sediment and collected with a 60 cm^3 syringe (2.5 cm diameter), immediately transferred to a centrifuge tube and kept on ice in the dark. Samples were subsequently frozen until later analysis (Grinham et al. 2007). Samples were analyzed at the Chesapeake Biological Laboratory according to the fluorometric method of Strickland & Parsons (1972).

To convert concentration to an integrated water column chlorophyll values were multiplied by the mean depth, 1.5 m, assuming a well mixed water column.

Results

The mean coastal bay-wide, active benthic chlorophyll a was 35 mg/m^2 in 2010 (number of sites = 24) with a standard deviation of 22. The minimum was 5.3 while the maximum active benthic chlorophyll *a* observed was 204. Highest abundances were in Isle of Wight and Sinepuxent Bays. These results are in line with data collected between 2002-2006 (Table 4.5.2).

Table 4.5.1 Average water column chlorophyll *a* (CHL) by bay segment (2010-2012 chl status, April-Nov) compared to average active benthic chlorophyll *a* (summer 2010).

Watershed	Water Column CHL (µg/L)	Integrated water column CHL (mg/m^2)	Benthic CHL (mg/m^2)
Assawoman	7.60	11.4	24.89
Isle of Wight	11.00	16.5	51.26
St Martin River	22.84	34.26	39.45
Sinepuxent	5.39	8.08	49.13
Newport	19.56	29.34	40.55
Chincoteague	5.30	7.95	24.15

Assawoman Bay – Average active benthic chlorophyll *a* was 24.89 mg/m^2 (n=4) (Table 4.5.1). The standard deviation among replicates at a site ranged from 2.1 – 7.9 mg/m^2. The minimum active benthic microalgae chlorophyll *a* value observed was 11.33 mg/m^2 and maximum observed value was 51.40 mg/m^2 (Figure 4.5.1). Total BMA (active chlorophyll plus pheophytin) biomass ranged 41.37 – 86.21 mg/ m^2.

Isle of Wight Bay – Average active benthic chlorophyll *a* was 51.26 mg/m^2 (n=6) (Table 4.5.1). The standard deviation among replicates at a site ranged from 2.2 – 18.2 mg/m^2. The minimum active benthic microalgae chlorophyll *a* value observed was 9.44 mg/m^2 and maximum observed value was 100.94 mg/m^2 (Figure 4.5.1). Total BMA biomass ranged 25.66 – 204.08 mg/ m^2.

St. Martin River – Average active benthic chlorophyll *a* was 39.45 mg/m^2 (n=3) (Table 4.5.1). The standard deviation among replicates at a site ranged from 1.5 – 10 mg/m^2. The minimum active chlorophyll *a* value observed was 19.27 mg/m^2 and maximum observed value was 80.51 mg/m^2 (Figure 4.5.1). Total benthic microalgaebiomass ranged 61.43 – 188.34 mg/ m^2.

Sinepuxent Bay –The average active benthic chlorophyll *a* was 49.13 mg/m^2 (n=1) (Table 4.5.1). The standard deviation among replicates was 8.7 mg/m^2. The minimum active benthic microalgae chlorophyll *a* value observed was 39.57 mg/m^2 and maximum observed value was 56.72 mg/m^2 (Figure 4.5.1). Total BMA biomass ranged 61.77 – 99.51 mg/ m^2.

Newport Bay – The active average benthic chlorophyll *a* was 40.55 mg/m^2 (n=2) (Table 4.5.1). The standard deviation among replicates at a site ranged from 1.1– 5.7 mg/m^2. The minimum active benthic microalgae chlorophyll *a* value observed was 15.02 mg/m^{2}and maximum observed value was 69.16 mg/m^2(Figure 4.5.1). Total BMA biomass ranged 54.41 – 121.45 mg/ m^2.

Chincoteague Bay – The average active benthic chlorophyll *a* was 24.15 mg/m^2 (n=9). The standard deviation among replicates at a site ranged from 1.6 – 11.3 mg/m^2. The minimum active benthic microalgae chlorophyll value observed was 5.31 mg/m^2 and maximum observed value was 41.33 mg/m^2 (Figure 4.5.1). Total BMA biomass ranged 13.99 – 106.82 mg/ m^2.

Discussion

Benthic microalgae play a significant role in the Coastal Bays and were more abundant than water column plankton biomass in some areas (Table 4.5.1). Interannual variability (Table 4.5.2) may be related to rainfall variations, water clarity differences and associated nutrient loading. Recommend benthic algae sampling (biomass and community species composition) be incorporated into monitoring and research efforts.

This data confirms the hypothesis that benthic microalgae are a major component of the autotrophic biomass throughout the Coastal Bays, with concentrations ranging from 5.3 to 204 mg/m^2. However, abundance was highly variable. Isle of Wight Bay had the highest average benthic microalgae while Chincoteague Bay had the lowest.

Benthic microalgae may have greater abundance than phytoplankton (per unit measure) in some areas of the Coastal Bays. When chlorophyll biomass is integrated over the depth of the water column, the average benthic microalgae biomass is greater. It is likely that benthic microalgae play a significant role in nutrient cycling within sediments, as well as being an important primary producer within the system. Benthic microalgae samples were limited and, due to the spatial and temporal patchiness of these organisms, additional samples would give a more accurate assessment. Further research is required to establish causes of variability and reliable measures of this metric to develop an effective monitoring tool.

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Figure 4.5.1 Distribution of active benthic chlorophyll during the summer of 2010.

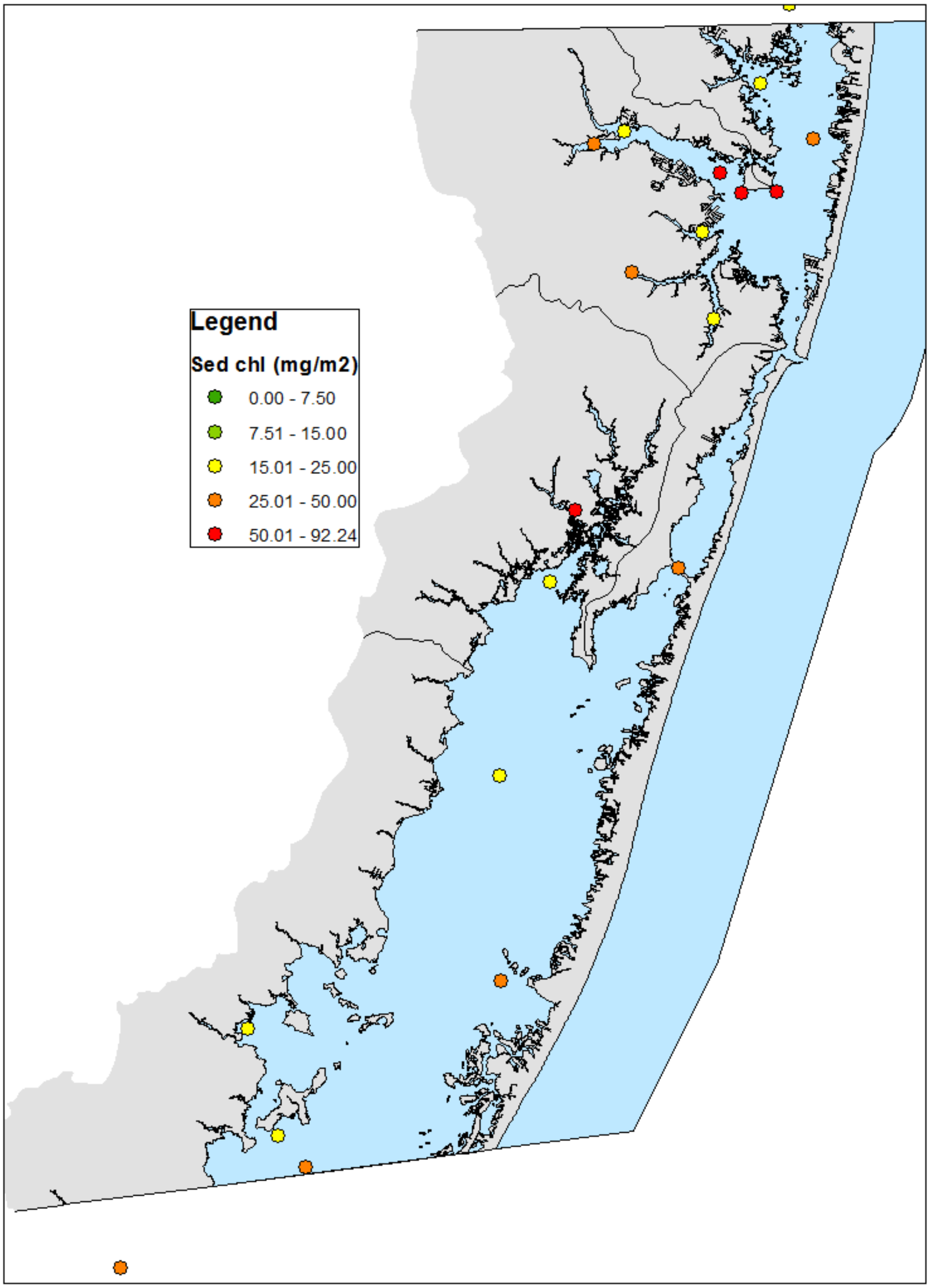

Table 4.5.2 Average benthic chlorophyll and range in the Maryland Coastal Bays, 2002-2010.

			TOTAL sediment chl a (mg/m2)			**ACTIVE sediment chl a (mg/m2)**		
Year	**N**	**reps**	min	max	**Average**	min	max	**Average**
2002	76	3	27	267	**73.8**	10	236	**31.6**
2003	152	3	10	312	**78.8**	0	294	**37.7**
2004	40	10	11	450	**77.1**	0	337	**32.4**
2005	20	8	22	317	**79.4**	6	224	**31.6**
2006	20	8	14	189	**57.1**	7	77	**20.4**
2010	25	3	47	150	**81.31**	12	92	**34.9**

Chapter 5.1

Seagrass abundance in the Maryland Coastal Bays

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Abstract
Seagrasses have significantly decreased in the Maryland Coastal Bays since 2005. The 2013 acreage represents the lowest acreage documented since 1991. Although seagrasses are found in four major segments of Maryland's Coastal Bays, they are not distributed evenly. Over 90% of all seagrasses occur along the Assateague Island shoreline. Overall watershed decreases have been between 35 and 86 percent since 2000 with Chincoteague Bay sustaining the greatest losses. Current goal attainment is only 25.5% (down from 71% attainment in 2001). Overall seagrass acreage peaked in 2001 (19,301 acres) and had significant decreases in 2005 and 2011. Current acreage is equivalent to that in 1991 signifying a 20 year regress.

Introduction
Submerged aquatic vegetation (SAV or seagrasses) have been monitored annually since 1986 through aerial surveys conducted by the Virginia Institute of Marine Sciences (VIMS) and funded by Maryland, Virginia and the federal government. General consensus among the scientific community is that, despite recent increases documented by the aerial survey, current seagrass levels are considerably lower than historic levels found in the early 1900s. In the early 1930s, eelgrass wasting disease virtually eliminated eelgrass (*Zostera marina*) along the east coast including areas in the southern Coastal Bays where it was the dominant species (Muehlstein 1989).

Water quality conditions play a critical role in seagrass distribution because they affect the amount of light they receive for growth (Stevenson *et al.,* 1993). In the Chesapeake Bay, water quality goals have been established based on depth (as an indicator of potential light availability)(Batuik et al 2000). Other important factors that may determine seagrass distribution in the Coastal Bays include percent organic content of the bay sediment (eelgrass prefers sediment with an organic content <5%) (Koch 2001).

The abundance and distribution of seagrasses are an important part of the Coastal Bays ecosystem. Seagrasses are used as a nursery for many species. Not only do seagrasses improve water quality by producing oxygen, absorbing excess nutrients and removing sediment from water, they also provide food and shelter for waterfowl, fish and shellfish. For example, research has shown that the density of juvenile blue crabs (*Callenectes* *sapidus*) is 30 times greater in grass beds than in unvegetated areas (Orth and Montfrans, 2002).

Management Objective: Increase seagrass abundance to goal levels by maintaining acceptable habitat conditions for seagrass expansion.

Seagrass Abundance Indicator: Seagrass abundance (acreage)
GOAL=27,041 acres

Embayment goals

Assawoman Goal =	1,745 acres
Isle of Wight Goal =	1,476 acres
St Martin River Goal=	48 acres
Chincoteague Goal =	20,400 acres
Newport Bay Goal =	341 acres
Sinepuxent Goal =	3,031 acres

Data Sets

Seagrasses have been monitored annually in the Coastal Bays by VIMS since 1986 using aerial photography techniques timed to occur during the peak growing season of SAV in the Coastal Bays (Orth et al 2014).

Analyses

VIMS digitization of aerial photos (Orth et al 2014); Maryland Department of Natural Resources (DNR) categorization into bay segment and goal development/assessment.

Status and Trends of Seagrass Abundance

Total seagrass coverage in the Coastal Bays following the 2013 survey is shown in Figure 5.1.1. Overall, 6,903 acres of seagrass were detected, a 10% decrease from 2012 and nearly 65% loss since 2001. Descriptions of abundance in each individual bay follow:

Assawoman Bay

In 2013, there were 111 acres of seagrass in Assawoman Bay representing 4% of the goal for that segment (Figure 5.1.2). Seagrass coverage had increased annually since first being documented in 1991 and peaked in 2010 at 932 acres (53% of established goal). In 2011, this bay saw a dramatic loss and coverage has remained low.

St. Martin River

In 2013, there were 1.19 acres of seagrass in St. Martin River representing a 2% of the goal for this segment (Figure 5.1.3). SAV first appeared in St. Martin River along the Isle of Wight Management Area in 1999 and peaked in 1999 at 4.4

acres. Grasses were wiped out in 2005 and 2011 (0 acres) but continue to have minimal coverage around the Isle of Wight Management Area.

Isle of Wight

In 2013, there were 121.19 acres of seagrass in Isle of Wight Bay representing 8% of the goal for this segment (Figure 5.1.4). Seagrass coverage increased annually since it first appeared in 1992, until 2010 peak abundance of almost 520 acres. In 2011, it experienced a major decline losing 485 acres. Acreage rebounded some in 2012 and remained over 100 acres in 2012.

Sinepuxent

In 2013, there were 1,274.22 acres of seagrass in Sinepuxent Bay representing 42% of this segments goal (Figure 5.1.5). Seagrass coverage peaked in 2004, with 2,282 acres and despite losses in 2005, remained fairly high until 2011 when coverage began a declining trend.

Newport

In 2013, there were 27.4 acres of seagrass in Newport Bay representing 8% of this segments goal (Figure 5.1.6). Seagrass coverage increased from 1990 when it first appeared to 2001 (peak 121 acres). Grasses are mostly located along the lower eastern shore of the bay. After 2001, grasses began to decline and in 2005 Newport Bay had significant decreases. However, grasses were regaining acreage through 2010 when a declining trend returned.

Chincoteague Bay

In 2013, there were 5,405 acres of seagrass in Chincoteague Bay representing 26.5% of the goal for this segment (Figure 5.1.7). This segment has experienced the largest loss in acreage from its peak of 16,349 acres in 2001. Since 2001 there has been a generally steady decrease in coverage (small increase in 2009 and 2010).

Seagrass Abundance Summary

Seagrasses are an important indicator of bay health. The largest distribution of seagrass in the Coastal Bays occurs in Chincoteague Bay (5,405 acres) (Figure 5.1.1) with Sinepuxent Bay having the best goal attainment (42%) (Figure 5.1.5). Distribution of seagrasses in the northern bays and Newport Bay is limited, presumably due to poorer water quality conditions (see Chapter 4 of this report).

Results for 2013 show that seagrass acreage decreased 26% from 9,319 acres in 2007 to approximately 6,903 acres in 2013 (Figure 5.1.8). Overall trends show that SAV acreage in the Maryland Coastal Bays peaked in 2001 (19,301 acres) and had significant decreases in 2005 and 2011. Current acreage is equivalent to that in 1991 signifying a 20 year regress (Figure 5.1.8).

Density is not currently an approved indicator by the scientific and technical advisory committee but was examined. Biomass has been reduced especially the densest beds, despite generally improving water quality trends. If water quality trends continue, seagrasses should also begin to show improvements. Some possible causes for decreasing seagrass are explored in Chapter 5.3.

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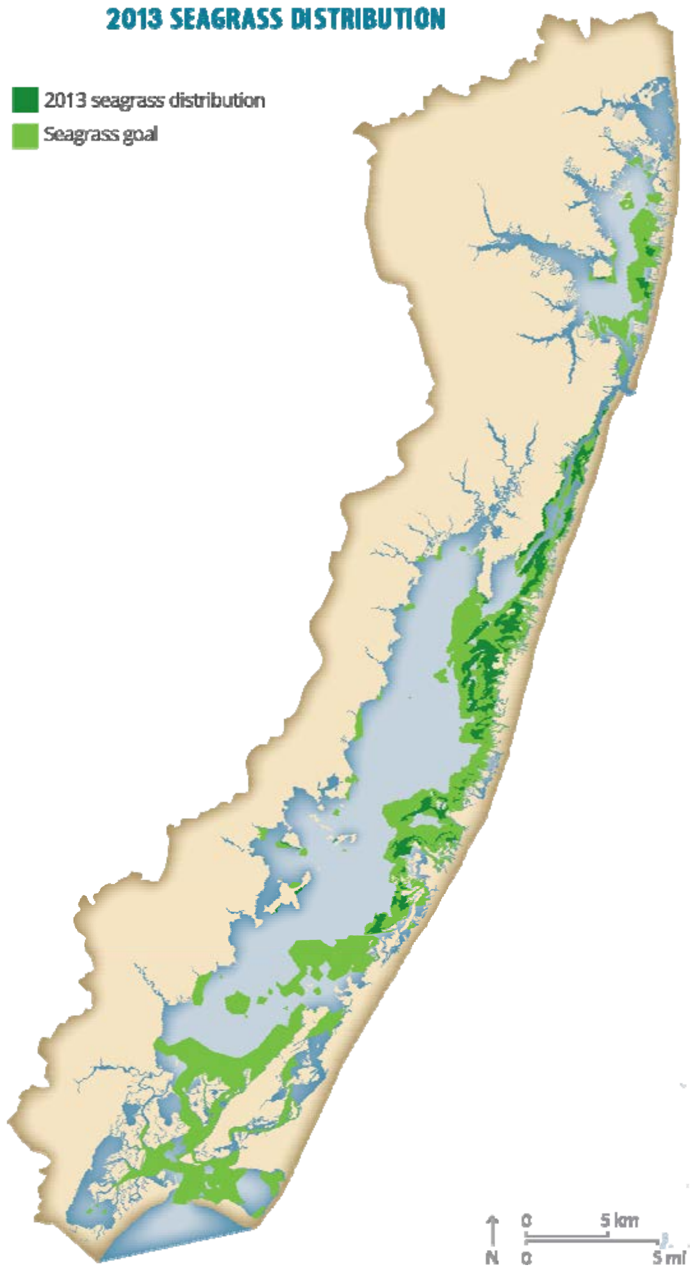

Figure 5.1.1 Seagrass goal (light green) compared to the 2013 distribution of seagrass coverage in the Coastal Bays (dark green) - Virginia Institute of Marine Science aerial survey.

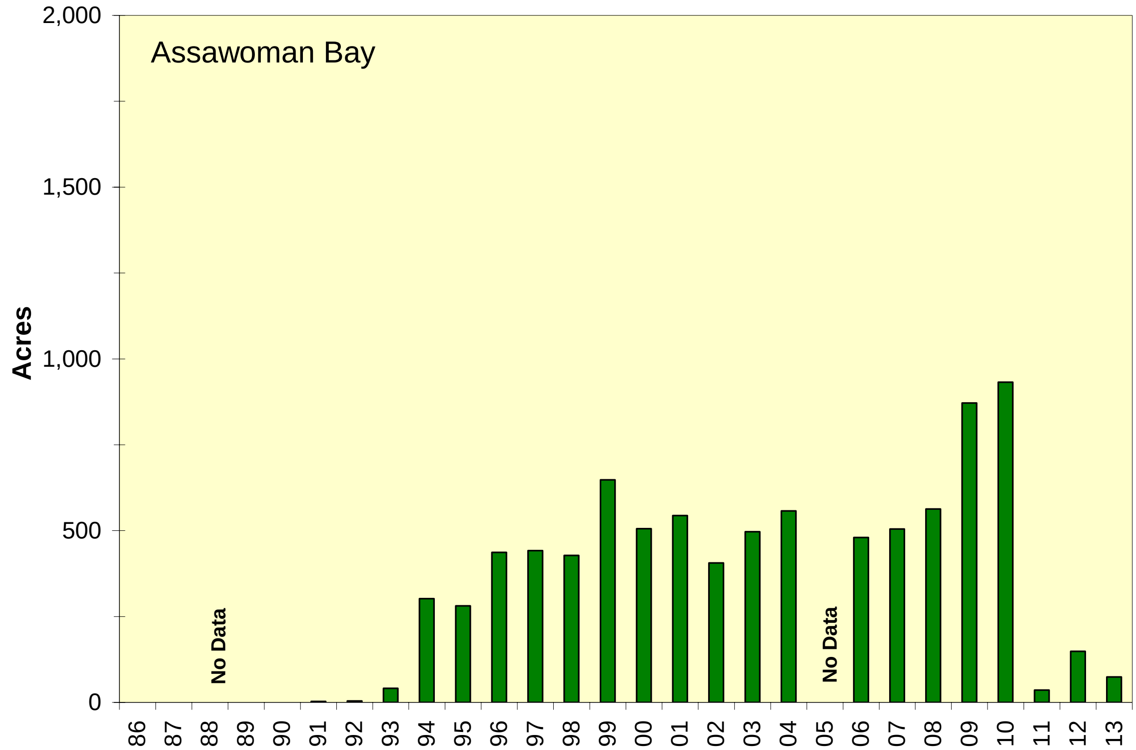

Figure 5.1.2 Annual seagrass acreage in Assawoman Bay 1986-2013. Seagrass goal is 1,745 acres.

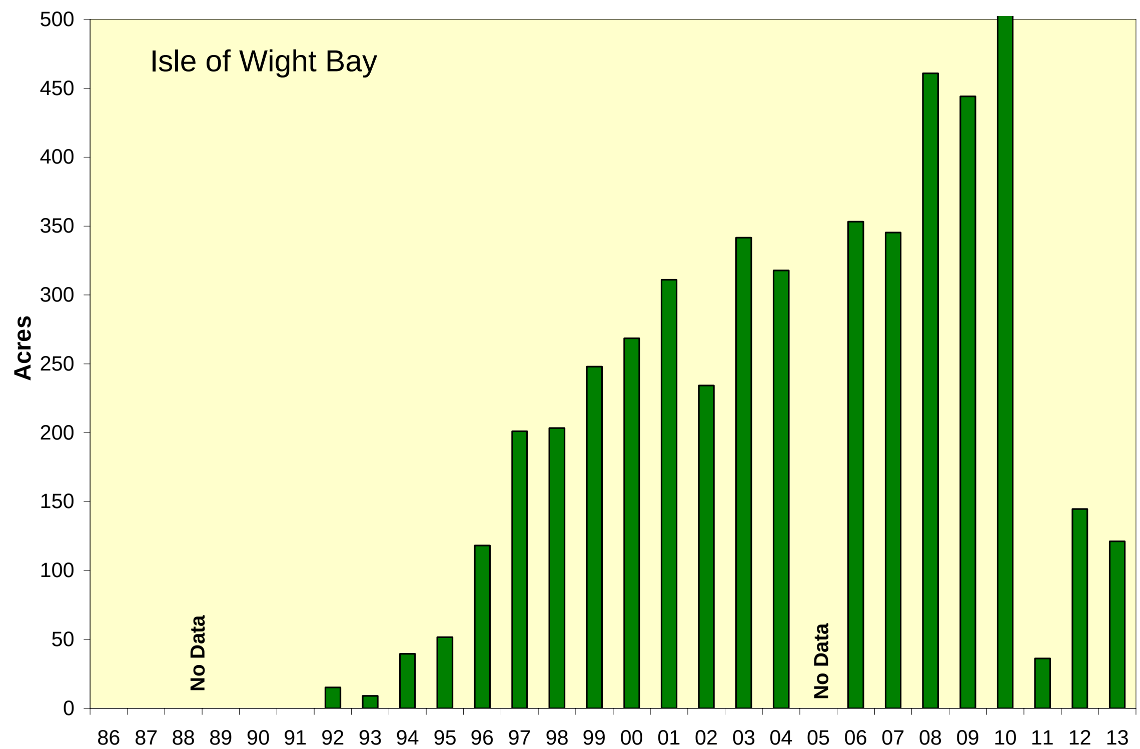

Figure 5.1.3 Annual seagrass acreage in Isle of Wight Bay 1986-2013. Seagrass goal is 1,476 acres.

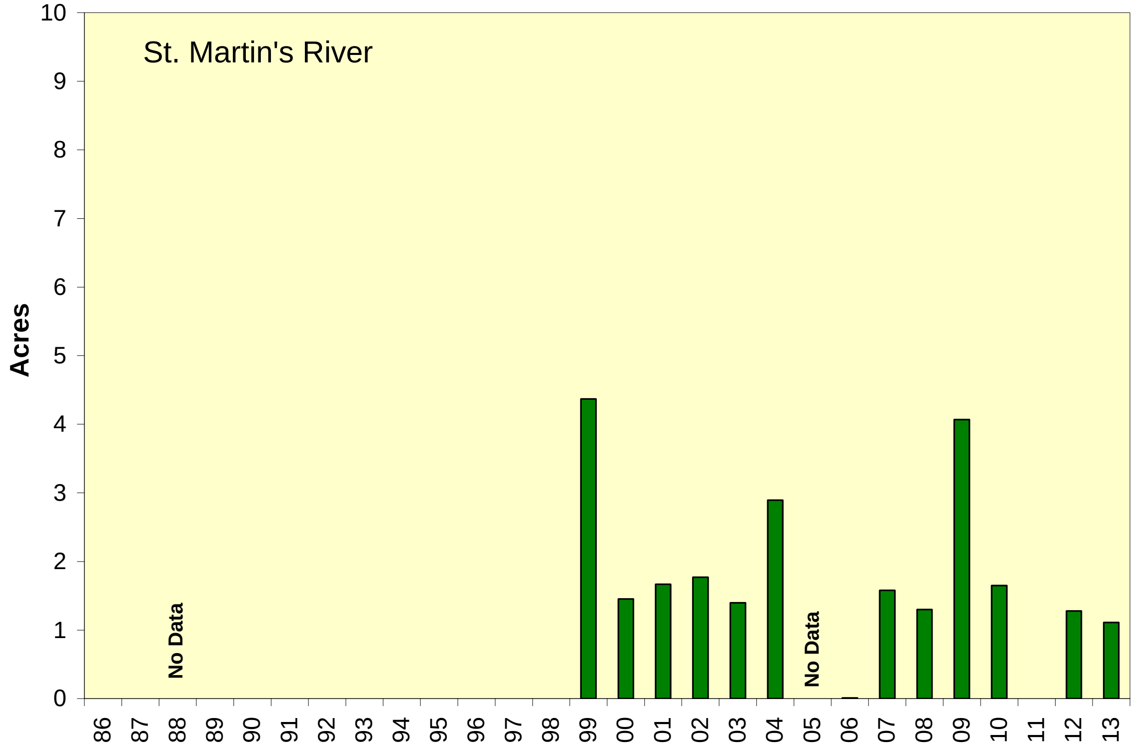

Figure 5.1.4 Annual seagrass acreage in the St. Martin River 1986-2013. Seagrass goal is 48 acres.

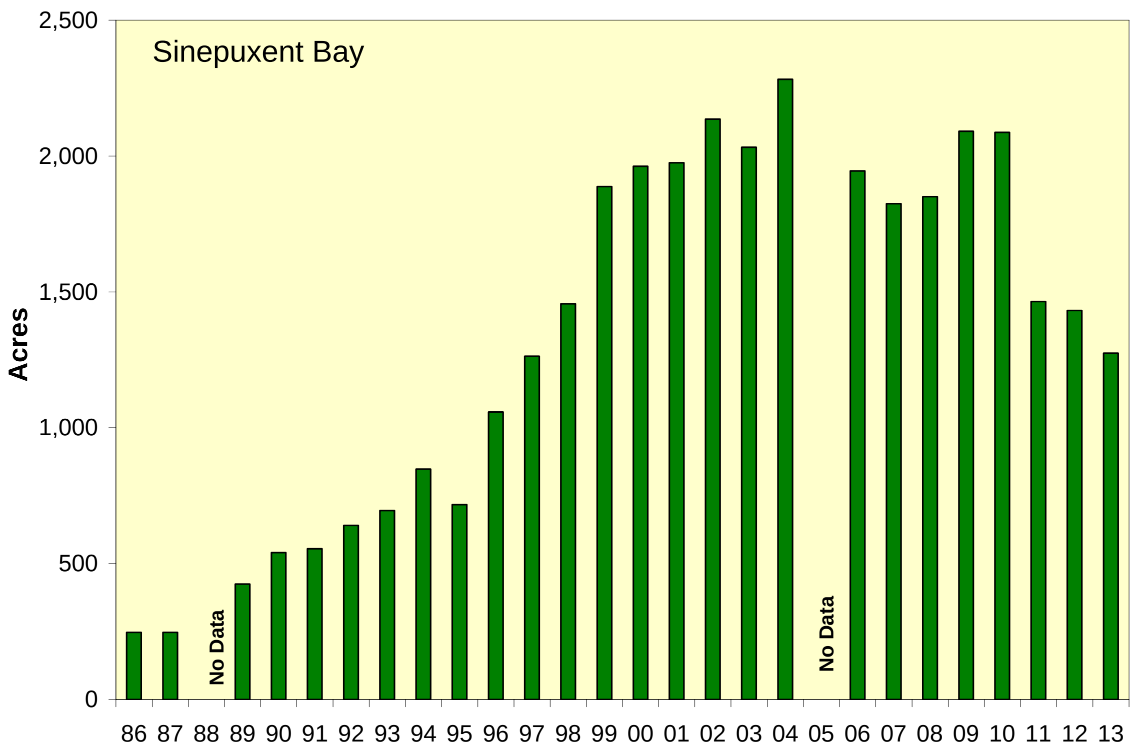

Figure 5.1.5 Annual seagrass acreage in Sinepuxent Bay1986-2013. Seagrass goal is 3,031 acres.

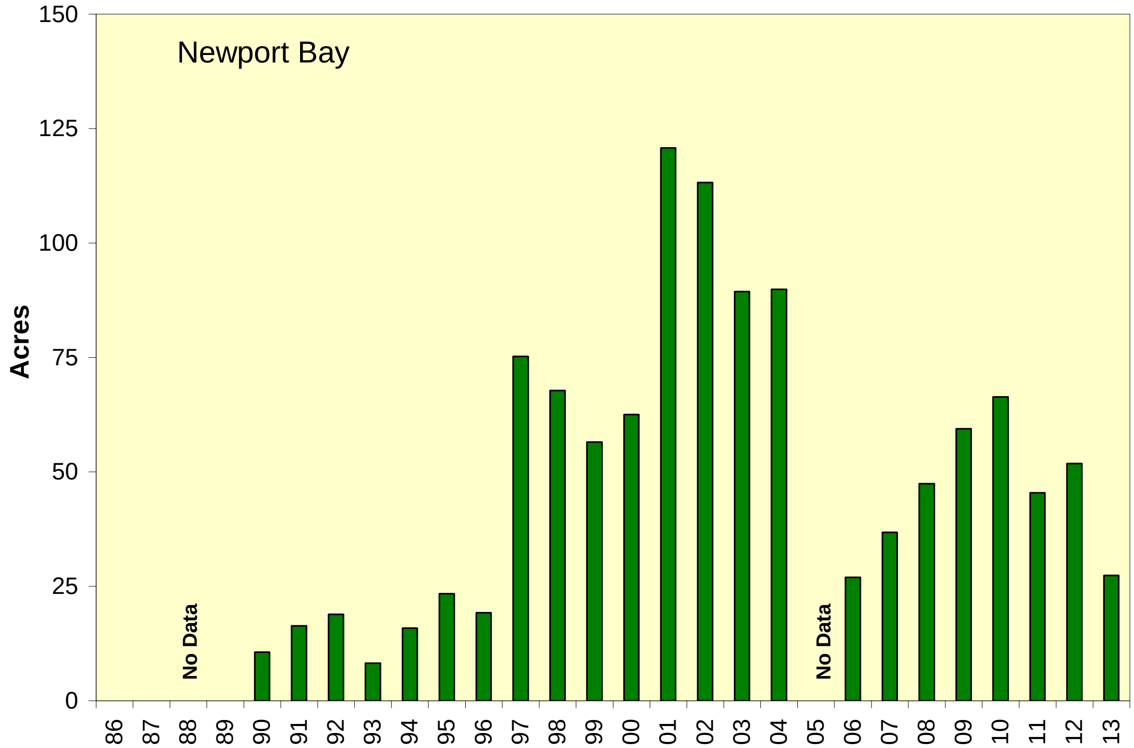

Figure 5.1.6 Annual seagrass acreage in Newport Bay 1986-2013. Seagrass goal is 341 acres.

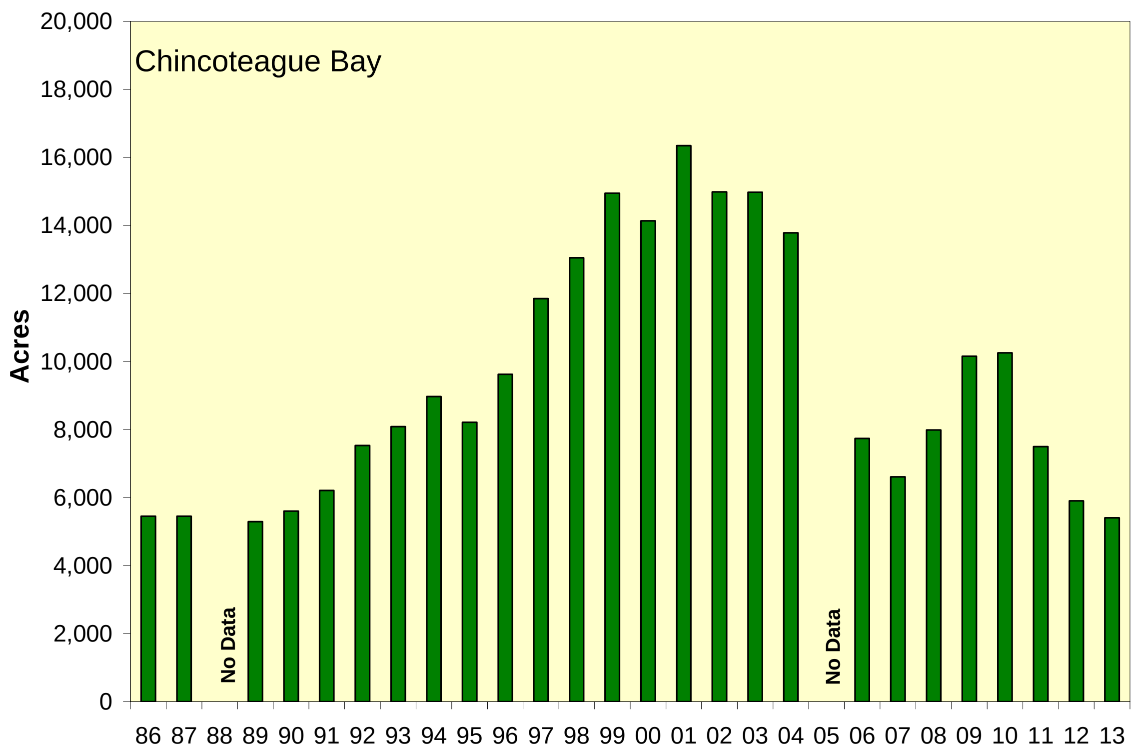

Figure 5.1.7 Annual seagrass acreage in Chincoteague Bay 1986-2013. Seagrass goal is 20,400 acres.

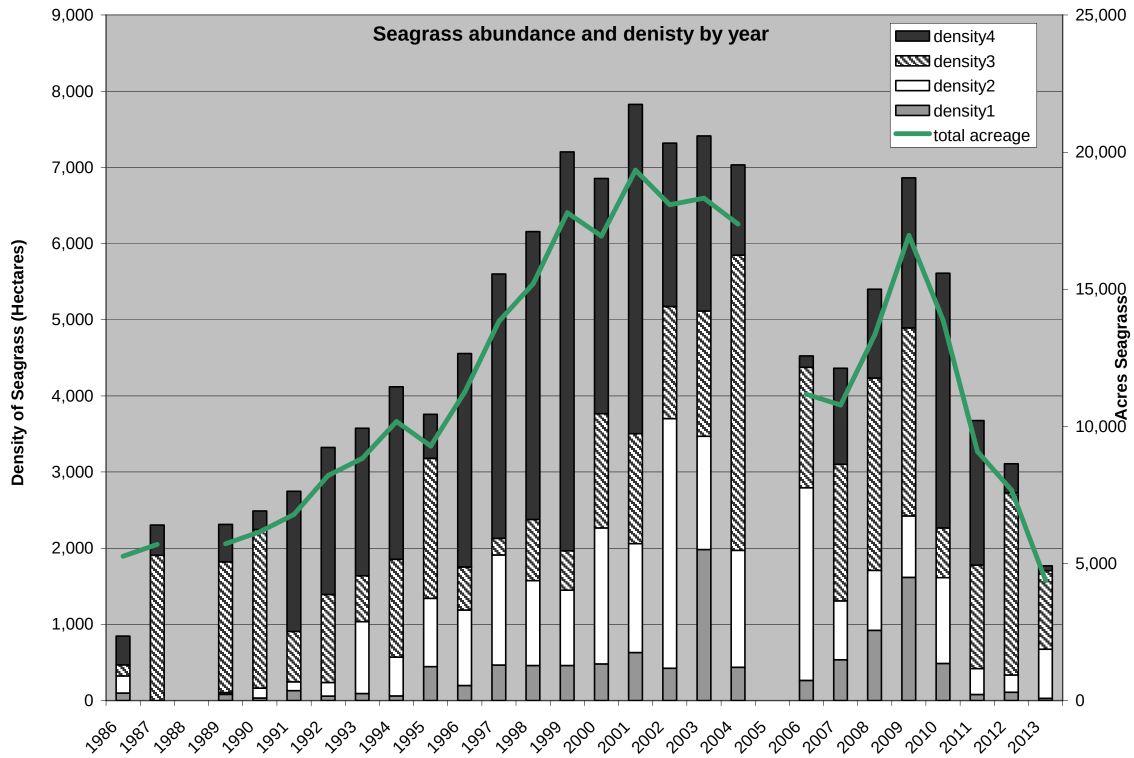

Figure 5.1.8 Hectares of seagrass by year (1986-2013) and density classes (density 1 <10% coverage; density 2 coverage =10-40%; density 3 = 40-70% coverage; density 4 >70% coverage).

Chapter 5.2

Development of a seagrass habitat suitability index for the Maryland Coastal Bays

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Abstract
The Coastal Bays submerged aquatic vegetation habitat index (SAVi) was developed to explain differences in seagrass distribution among the major watersheds. The SAVi summarizes the attainment of five habitat criteria (total nitrogen, total phosphorus, chlorophyll, total suspended solids and Secchi depth). When the SAVi was compared to SAV goal attainment in each segment 2011-2013 the relationship was poor ($r^2 = 0.17$). Therefore, three additional indices of SAV habitat were compared to the seagrass goal attainments in each watershed between 2011 and 2013. The water quality index (WQI) presented in Chapter 4.4 used total nitrogen (TN), total phosphorus (TP), chlorophyll a (CHL) and dissolved oxygen (DO) showed the best relationship to SAV goal attainment ($r^2 = 0.78$), followed closely by a new SAV index that used dissolved inorganic nitrogen, dissolved inorganic phosphorus and chlorophyll ($r^2 = 0.75$) and a modified water quality index using TN, TP and chlorophyll ($r^2 = 0.71$).

Introduction
Seagrasses are ecologically important resources which are sensitive to changes in water quality. Certain environmental variables that are measured in standard water quality monitoring programs, may help explain differences in seagrass distribution (Dennison *et al*, 1993). Previous studies in the Maryland Coastal Bays have suggested that seagrass distribution and abundance may be limited by high nutrient loading rates (Boynton *et al*, 1996). Therefore, assessing water quality thresholds based on seagrass habitat criteria provides information about potential maintenance of the ecosystem services associated with aquatic grass meadows.

A seagrass habitat suitability index (**SAVi)** was developed in an attempt to summarize habitat criteria attainment for all five parameters on a bay segment scale which could be compared to the status of seagrasses in each segment. The SAVi was compared to seagrass goal attainment. The Secchi threshold was adapted since Secchi disk readings are often "on the bottom" due to the shallow nature of the seaside lagoons indicating sufficient light for plant growth. In addition, total suspended solids were analyzed as an indicator of light availability. Additionally, the WQI (TN, TP, CHL and DO) used in Chapter 4.4 was also compared to the seagrass goal attainment as well as a new SAV index (DIN, DIP, CHL) and a new water quality index (TN, TP and CHL).

<u>Seagrass Habitat Criteria</u>
Although seagrasses are found in all four major segments of Maryland's Coastal Bays, they are not distributed evenly. Over 90% percent of seagrasses in the coastal lagoons

occur along the Assateague Island shoreline. In the northern bays, seagrass abundance is limited (see chapter 5.1) presumably due to reduced water quality from human activities.

Increased sediment and nutrient inputs from point and non-point sources decrease the amount of sunlight from reaching the seagrasses and are considered the primary threat to their health. Seagrasses in the Coastal Bays may also be damaged by excessive macroalgae, Brown Tide and recreational and commercial boating activity. Natural factors, such as sediment type and wave action also influence the health and location of seagrass beds.

Management Objective: Increase seagrass abundance by maintaining acceptable habitat conditions for seagrass expansion.

Indicator: SAVI = 1.0 (100% attainment)

Seagrass Habitat Indicators:

***Draft* Habitat Indicator 1:** Chlorophyll *a* < 15 µg/L
***Draft* Habitat Indicator 2:** Dissolved Inorganic Nitrogen < 0.15 mg/L
***Draft* Habitat Indicator 3:** Dissolved Inorganic Phosphorus < 0.02 mg/L
***Draft* Habitat Indicator 4:** Total Suspended Solids < 15 mg/L
***Draft* Habitat Indicator 5:** Secchi >0.966 m or on bottom (>40% of time)

***Draft* Seagrass Habitat Index:** Index = 1.0

Data Sets

Monthly data from 41 Maryland Department of Natural Resources (DNR) and 18 Assateague Island (ASIS) National Park Service water quality stations was compiled for a 3-year time period (2011-2013). The indicators that were used to determine seagrass habitat criteria followed those adopted for the Chesapeake Bay and included Secchi depth, chlorophyll *a* concentration (chl *a*), total suspended solids (TSS), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP) (Batiuk et al. 2000). Habitat indicators use a median value of a three year period for all parameters during the SAV growing season (March – November).

Analyses

The primary growth of seagrasses in the Coastal Bays occurs from March through November. The growing season is based on the combined temperature requirements for growth of the two species of seagrass species present: *Zostera marina* (March – May and October – November) and *Ruppia maritima* (April - October). Median values for each indicator (except Secchi depth; see below) at each station were evaluated against accepted Environmental Protection Agency (EPA) Chesapeake Bay Program criteria (draft habitat indicators above) over the seagrass growing season for the combined three-year period. Although these were originally established for the Chesapeake Bay, work by Valdez *et al* (1998) and Lea *et al* (2003) suggest that the nutrient thresholds are similar in the Coastal Bays; however, the total suspended solids (TSS) and Secchi may be different.

Because the Secchi disk was frequently visible on the bottom, traditional median values could not be used. Specifically, median Secchi depths would have masked measurements "on bottom" thus suggesting conditions to be worse. For the current analyses, bottom measurements were determined to always indicate adequate seagrass light penetration. Therefore, a percentage of samples exceededing the Secchi threshold over the three-year period was adopted. Samples designated as "on bottom" were always included as meeting the threshold.

Attainment of habitat criteria (except Secchi depth) was tested by comparing the 3-year medians against the individual criteria. Each of the five criteria was determined to either pass or fail the individual criteria. The sum of the indicators that passed was divided by the total number of indicators (five) and an unweighted SAV index was determined for each station. An average of the SAV indices for all the stations in a bay segment was then calculated and compared to SAV goal attainments.

Index Analysis

To summarize SAV habitat criteria attainment, standard water quality variables measured between 2011 and 2013 were compiled into a suitability Index (SAVi). The index was calculated for each station (Figure 5.2.1) and also for each bay segment (Table 5.2.2). This index was based on compliance of measured water quality variables (Chlorophyll *a*, dissolved inorganic nitrogen, dissolved inorganic phosphorus, total suspended solids and Secchi depth) to established thresholds for survival of seagrasses (Table 5.2.1). Index values range from zero (no thresholds for seagrass survival attained) to one (all thresholds for SAV survival met). This approach of summarizing compliance of water quality variables with threshold values has previously been carried out to compare U.S. mid-Atlantic estuaries as well as tributaries within the Chesapeake Bay (Kiddon *et al*, 2003; Jones *et al*, 2003).

Table 5.2.1: Variables and threshold values used in the calculation of an submerged aquatic vegetation, SAV, index for Maryland Coastal Bays (1: Dennison *et al*, 1993; 2: Stevenson *et al*, 1993).

Variable	Threshold value	Reference
Chl a	$< 15\ \mu g\ L^{-1}$	1, 2
Dissolved inorganic nitrogen	$< 0.15\ mg\ L^{-1}$ ($11\ \mu M$)	1, 2
Dissolved inorganic phosphorus	$< 0.02\ mg\ L^{-1}$ ($0.64\ \mu M$)	1, 2
Total suspended solids	$< 15\ mg\ L^{-1}$	1, 2
Secchi depth	> 0.96M >40% of the time	1

For each station with greater than 10 records for each variable, medians were calculated for each variable. Only sampling occasions in March through November during 2001 to 2003 were included to represent the growth season of *Zostera marina* and *Ruppia maritima* the dominant seagrass species. Median values for each variable were compared to threshold values and scored as one (meets criteria) or zero (fails to meet criteria). These scores were summed for all variables and divided by the number of variables to result in a unitless index value ranging from zero to one for each sampling location. An index value of zero indicated that a site met none of the criteria, while a score of one indicated a site that met all habitat criteria. Once index values were calculated for each site, means were calculated for all sites within several reporting regions and are presented by measured variable and index values in tables 5.2.3 and5.2.4. Error associated with mean index values in these cases represents variation between sites, within a reporting region (and does not account for temporal variation).

SAV Index Status

Assawoman Bay

In Assawoman Bay, the open bay station nearest existing seagrass beds (XDN4851) met all but one habitat criteria (Secchi failed) (Table 5.2.2). The majority of stations, 67%, failed the Secchi criteria while all stations but one passed TSS (Table 5.2.4). Assawoman Bay tied for the highest SAVi (0.8) but one of the lowest SAV goal attainments (5%) (Table 5.2.3).

St. Martin River

The St. Martin River shows minimal agreement with the chlorophyll and Secchi seagrass habitat thresholds while DIN and DIP water quality variables failed in only some of the headwater sites (Table 5.2.2). Total suspended solids failed at half the sites, while the Secchi threshold was only achieved at one station. The SAVi was rather high (0.51) given there is currently minimal seagrass growing within this region (2% of SAV goal attainment) (Table 5.2.3).). (Table 5.2.4)

Isle of Wight

In Isle of Wight Bay nutrient thresholds only failed in the headwaters of Turville Creek. Total suspended solids and Secchi conditions failed at two sites (open bay and near the inlet) while light limitation was also indicated by Secchi in Herring and Turville creeks (Table 5.2.2). Isle of Wight Bay had the second highest SAVi (0.80) but met only 7% of the SAV goal (Table 5.2.3). (Table 5.2.4)

Sinepuxent

All stations in Sinepuxent Bay meet all of the water chemistry criteria (chlorophyll, DIN and DIP); however, failed light requirements (both TSS and Secchi) at ASIS 17 and ASIS 18 and Secchi at ASIS 1 (Table 5.2.2). Noticeably absent are seagrass beds around the two stations nearest the Ocean City Inlet (ASIS 1 and ASIS 17). ASIS 1 is the West Ocean City Harbor. The strong currents coming from the inlet probably make the area unsuitable for SAV growth and may also contribute to the elevated TSS levels at site ASIS 17 (Table 5.2.2). Yet, site ASIS 18 sits at the edge of a large bed that may be decreasing slightly in size and density. Sinepuxent Bay had the highest SAVi score (0.80) and met 46% of its seagrass goal (Table 5.2.3). All dissolved nutrient and chlorophyll thresholds were met (Table 5.2.4).

Newport

Stations in the upper tributaries of Newport Bay failed one or more criteria (Table 5.2.2). DIP was met at nearly all stations; however, attainment of Secchi depth criteria was not attained at any of the stations (Table 5.2.4). The two stations in the bay proper (ASIS 3 and 4) met all thresholds (Table 5.2.2). However, they barely met the Secchi attainment. Overall, Newport Bay was only slightly better than St Martin River based on the SAVi (0.62) and SAV goal attainment was 12% (Table 5.2.3).

Chincoteague

Generally, stations with a majority of criteria met were in close proximity to existing seagrass beds (ASIS 6, 8 and 15); however, both ASIS 8 and 15 failed the Secchi threshold. The majority of stations, including those not near seagrass beds, demonstrated generally good conditions for seagrass growth (Table 5.2.2) except that 71% failed to attain Secchi thresholds. Six stations also failed TSS thresholds (35%) and four failed DIP threshold (24%). The bay averaged SAVi for Chincoteague was ranked forth (0.74) yet this bay had the highest SAV goal attainment of 31% (Table 5.2.3). The northern part of Chincoteague Bay passed all of the dissolved nutrient and chlorophyll thresholds but struggled with light (TSS and Secchi) while the southern portion of the bay also struggle with light (Secchi) and dissolved phosphorus (Table 5.2.4).

Seagrass Habitat Criteria Summary

Regressions of four indices of water quality to seagrass goal attainment by segment was completed for 2011-2013. Results show the SAV index (DIN, DIP, CHL, Secchi and TSS) had an r^2 or 0.169. The water quality index, WQI, combines TN, TP, CHL and DO only had a r^2 of 0.7802. The new WQI used TN, TP, light and had an r^2 of 0.7475. The last index tested (yellow triangles) was the WQI with dissolved oxygen removed (TN, TP, CHL) had an r^2 of 0.7097.

However, indicators of water quality (see figure 4.1.3) suggest no trend prior to the 3-year period used for this analysis. Another possible explanation could be that since this SAV habitat analysis only includes water quality and clarity indicators, physical habitat characteristics conducive to seagrass growth, such as sediment characteristics or hydrology are not considered. Sediment type as well as other factors can play roles in the presence of seagrass.

The low proportions of Secchi depth percentages across all stations regardless of seagrass presence serves as a warning that criteria developed for the Chesapeake Bay may not suffice. Secchi depth data was found to be problematic due to the lack of quantitative measure associated with instances of "on bottom" measurements. In fact, at some stations the minimum criterion exceeded the station depth. In response to this issue, a percentage time Secchi passed the criterion was adopted. All "on bottom" measurements were considered to have adequate water clarity for SAV growth and were grouped as passing the criterion. Secchi depth results are reported simply as the percentage of measurements over the three-year period that passed the criterion. Additionally coefficients to convert Secchi to light attenuation (K_d) are thought to be variable in the Coastal Bays based on the dominant sediment material resuspended in the water column.

Summary

The SAV Index by region appears to be less representative than the Water Quality Index (Figures 5.2.1 and 4.4.2). Although both used "seagrass habitat criteria" there was a significant difference between seagrass threshold achievement for total nutrients (see Chapter 4.4, specifically Table 4.4.2) vs. dissolved nutrients (Table 5.2.3). Future evaluation of habitat criteria should include total nutrients, since more stations met the inorganic nutrient criteria (Table 5.2.4) while demonstrating relatively poor status when analyzed for total nutrients (see

Chapter 4.1, specifically Figures 4.1.1 and 4.1.2). However, as a general first iteration of SAV habitat testing, these results tend to follow the spatial pattern of SAV distribution.

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Bay Segment	Station	SECCHI	TSS	CHLA	DIP	DIN
Assawoman Bay	XDN4851	38.5%				
	XDN5737	35.5%				
	XDN6454	35.5%				
	XDN7261	64.5%				
	XDN7545	51.5%				
	GET0005	32%				
St. Martin River	BIH0009	ND				
	BNT0012	ND				
	BSH0008	14.8%				
	BSH0030	0%				
	MXE0011	ND				
	SPR0002	14.8%				
	SPR0009	18.5%				
	XDM4486	13.5%				
	XDN3724	41.4%				
	XDN4312	33.3%				
	XDN4797	25.9%				
Isle of Wight Bay	HEC0012	25.9%				
	MKL0010	31.3%				
	TUV0011	25%				
	TUV0019	59.3%				
	TUV0034	ND				
	XDN0146	37%				
	XDN2340	37%				
	XDN2438	48.1%				
	XDN3445	80%				
Sinepuxent Bay	ASIS 1	33.3				
	ASIS 2	47.2				
	ASIS 16	44.4				
	ASIS 17	36.1				
	ASIS 18	38.9				
Newport Bay	AYR0017	0%				
	MSL0011	0%				
	NPC0012	9.9%				
	NPC0031	0%				
	TRC0043	25.9%				
	TRC0059	36%				
	XCM4878	23.1%				
	BMC0011	ND				
	BOB0001	ND				
	KIT0015	ND				
	ASIS 3					
	ASIS 4					

Bay Segment	Station	SECCHI	TSS
Chincoteague Bay	XBM1301	48%	
	XBM3418	42.3%	
	XBM5932	23.1%	
	XBM8149	15.4%	
	XCM0159	14.8%	
	XCM1562	18.5%	
	ASIS 5	22.2	
	ASIS 6	22.2	
	ASIS 7	44.4	
	ASIS 8	38.9	
	ASIS 9	47.2	
	ASIS 10	58.3	
	ASIS 11	19.4	
	ASIS 12	27.8	
	ASIS 13	36.1	
	ASIS 14	30.6	
	ASIS 15	38.9	

Met	Not Met	Insufficien
		####

Table 5.2.2 Coastal Bays seagrass habitat criteria test results for MD Coastal Bays stations 2011-2013 (March-November). The Secchi depth test is the percentage of samples (station per month per year) passing either the 0.966 m criterion or with samples that were "on bottom" which automatically pass (sufficient light on bottom). For all other indicators, medians compared to threshold values are summarized by station using the color-shaded chart (green = threshold met and red = threshold not met).

Table 5.2.3 SAV suitability Index by reporting region calculated from median values (March – November; 2011-2013 vs 2001-2003).

Region	n (sites)	SAVI 11-13	Health	SAVI 01-03
Assawoman	6	**0.80**	Good	0.63
St Martin	11	**0.56**	Poor	0.41
Isle of Wight	9	**0.80**	Good	0.77
Sinepuxent	5	**0.80**	Good	1.00
Newport	12	**0.62**	Poor	0.48
Chincoteague	17	**0.74**	Good	
North Chincoteague	6	**0.67**	Good	0.77
South Chincoteague	11	**0.78**	Good	0.80

Table 5.2.4 SAV suitability Index scores, by measured variable, based on median values (March – November; 2011-2013). Zero means all failed threshold and score of one means mean passed at all sites.

	Secchi	TSS	CHL	DIP	DIN
Assawoman	0.33	0.83	1.0	1.00	0.83
St Martin River	0.36	0.55	0.45	0.82	0.64
Isle of Wight	0.44	0.78	1.0	0.89	0.89
Sinepuxent	0.40	0.60	1.00	1.00	1.00
Newport	0.42	0.58	0.58	0.92	0.58
Chincoteague	0.29	0.65	1.0	0.76	1.0
North Chincoteague	0.00	0.33	1.00	1.00	1.00
South Chincoteague	0.45	0.82	1.00	0.64	1.00

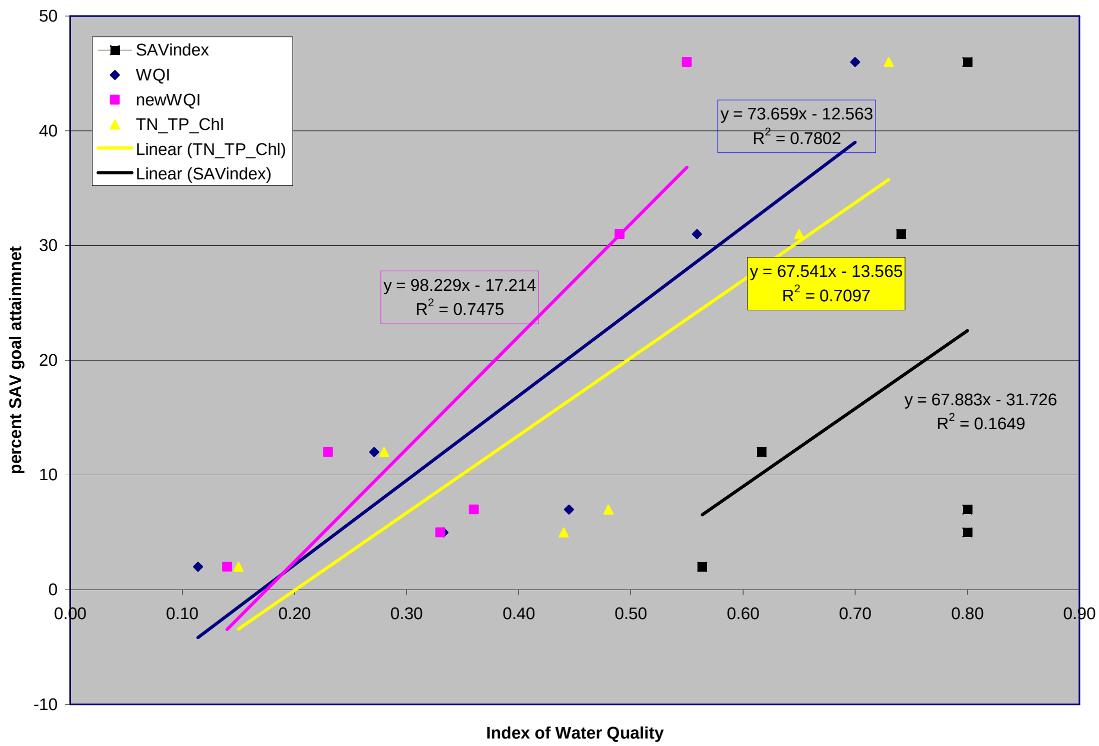

Figure 5.2.1 Regressions of four indices of water quality to SAV goal attainment by segment for 2011-2013. The SAV index (black squares) includes DIN, DIP, CHL, Secchi and TSS. The water quality index, WQI, used in Chapter 4.4 (blue diamonds) combines TN, TP, CHL and DO. The new WQI (pink squares) uses TN, TP, light. The last index tested (yellow triangles) was the WQI with dissolved oxygen removed (TN, TP, CHL).

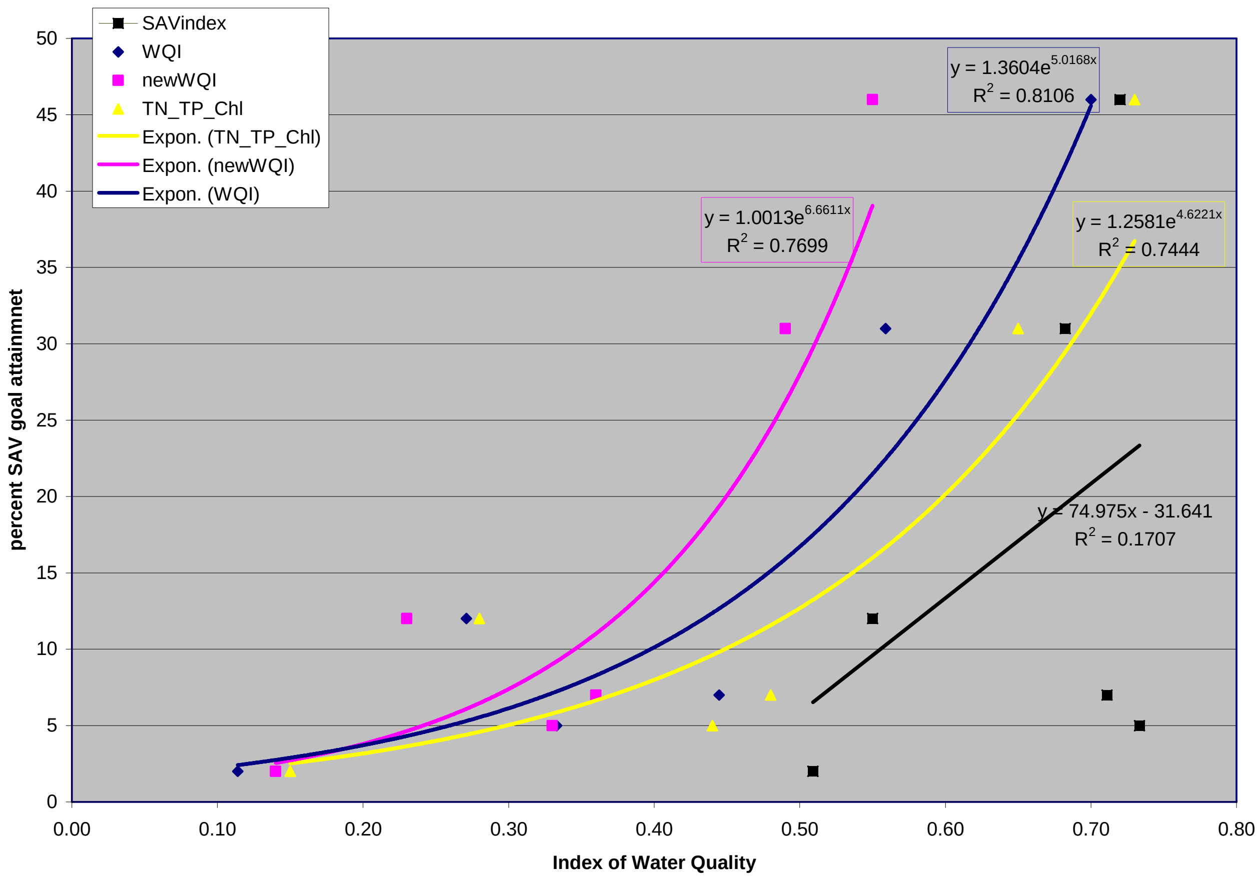

Figure 5.2.2 Exponential regressions improve model fit. The WQI, water quality index, used in chapter 4.4. (TN, TP, CHL, DO); new WQI includes TN, TP and light (from what?) and the last index was the WQI minus DO (TN, TP and CHL). SAVindex includes DIN, DIP, CHL, TSS and Secchi.

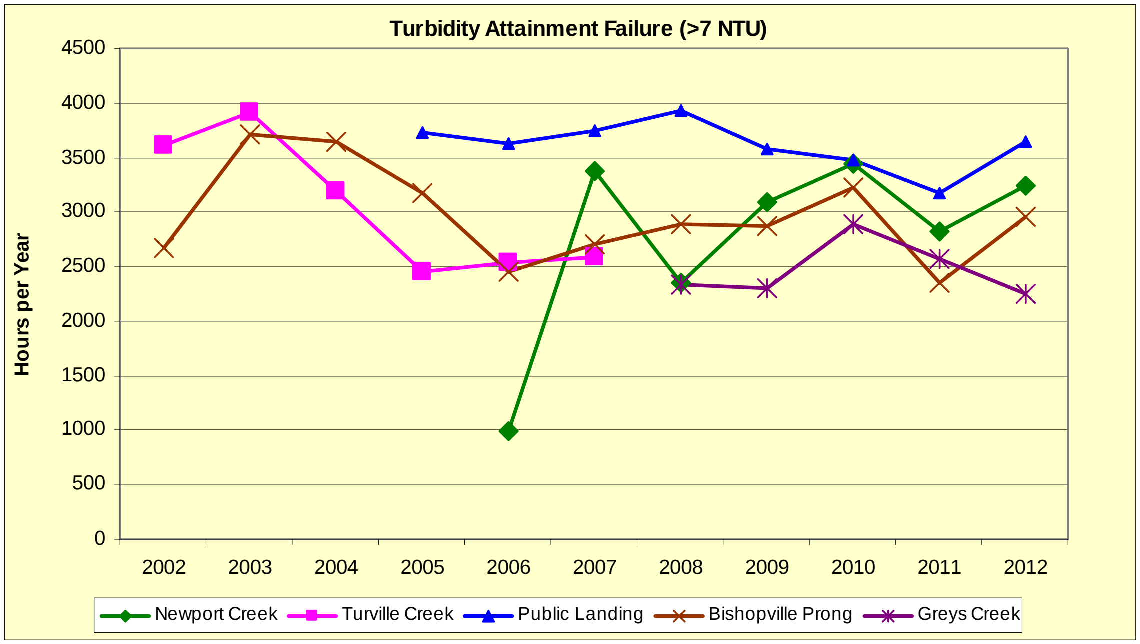

Figure 5.2.3 Failure of turbidity attainment in the coastal bays based on continuous monitoring. Shows highly turbid natural environment (7 NTU ~ 15mg/L TSS- Boyton report).

Chapter 5.3

Long-term Changes in Water Clarity and Temperature in Maryland's Coastal Bays

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Abstract
The 2013 acreage represents the lowest seagrass coverage documented in the Maryland Coastal Bays since 1991. Seagrasses had been recovering in most embayments after drastic losses in 2005. However, large losses have occurred since 2010 despite local improvements in water quality. Given the lack of seagrass response to suitable habitat conditions, additional environmental factors, including water clarity and temperature, were investigated to determine potential impacts on the recent loss. Overall, both water clarity measurements (Secchi depth and K_d) showed significant improvements from 2003 to 2013. However, current water clarity conditions exceed seagrass thresholds. The relationship between Secchi depth and light extinction (K_d) significantly decreased during the ten year analysis period, suggesting changes in light quality have occurred over time. Because this relationship has changed over time and varies by embayment, a Secchi depth/Kd conversion ratio should be avoided. Exceedance of eelgrass water temperature thresholds was greatest during 2010-2012 and most significant in Chincoteague Bay and St. Martin River. Stress from high water temperatures coupled with water clarity above threshold levels likely inhibited the recovery of eelgrass.

Introduction
Light attenuation is an important factor governing the abundance and distribution of seagrasses (submerged aquatic vegetation or SAV) in coastal ecosystems. Nutrient and sediment pollution can cloud the water and cause algal blooms which block sunlight from reaching seagrasses. Water quality trends in the Coastal Bays show mostly improving conditions for nutrients (Chap. 4.1) and algal blooms (Chap. 4.2). However, seagrasses have been declining in all coastal embayments regardless of improving habitat conditions in recent years.

Long-term declines in water clarity (K_d and Secchi depth) have been documented in the Chesapeake Bay (Gallegos et al., 2011 and the Maryland Department of Natural Resources's (DNR)Tributary Water Quality and Habitat Assessments). It is hypothesized that despite improving nutrient trends (see Chapter 4 of this report); similar long-term water clarity declines are contributing to the lack of seagrass response in Maryland's Coastal Bays. This analysis examines the long-term (2003-2013) temporal and spatial variability in water clarity data (K_d and Secchi depth).

Impacts of high water temperature stress on eelgrass include the disruption of photosynthetic and metabolic processes (Evan et al., 1986; Marsh et al., 1986; Zimmerman et al., 1989; Nejrup and Pedersen, 2008). Water temperatures above 25^{o}C have been shown to stress eelgrass (Rasmussen, 1977) and eelgrass die-backs have been reported when water temperatures exceed

30°C (Orth and Moore, 1986; Moore and Jarvis, 2008). The distribution of eelgrass can shift as a result of reduced water clarity and increased temperature stress. Long-term temperature impacts can lead to seagrass community changes, especially with increases in the frequency and intensity of extreme weather events.

Management Objective: Increase seagrass abundance by improving and maintaining acceptable habitat conditions for seagrass expansion.

Indicator: K_d and Secchi depth changes over time. *Indicate changes in water clarity.*
Temperature >30°C *Indicates stress to eelgrass.*

Data Sets

Monthly photosynthetically active radiation (PAR), Secchi depth, total suspended solids (TSS) and chlorophyll *a* (chl *a*) data were obtained from 18 National Park Service at Assateague Island (ASIS) water quality stations from 2003-2013, except 2009, and 24 DNR long-term monitoring stations from 2003-2013. Light attenuation, K_d, data was calculated from the PAR data using the 2-point SAV method (Michael et al., 2014). Secchi data was checked to determine if sat on bottom. If the Secchi sat of the bottom it was excluded from the analyses. Secchi depths were then multiplied by the calculated Kd for Secchi*Kd parameter.

Continuous monitoring data for temperature was collected every 15 minutes at four sites in the Coastal Bays (NPC0012 in Newport Bay, XBM8828 in Chincoteague Bay, XDM4486 in the St Martin, XDN6921 in Assawoman Bay) during 2007-2013.

Analyses

Monthly station data was averaged by embayment (Assateague Bay, St. Martin River, Isle of Wight Bay, Sinepuxent Bay, Newport Bay, and Chincoteague Bay) and analyzed by general linear model (GLM), with year as a continuous variable and month as a categorical variable to allow for seasonality (Gallegos et al., 2011).

The amount of time that the temperature was above 30°C was calculated by adding up the number of 15 minute measurements from continuous monitoring sites (measured with YSI 6600 instrument) in the Coastal Bays during the SAV growing season (March-November).

Water Clarity and Temperature exceedances

Assawoman Bay

Significant improvements in both Secchi depth and K_d over time.
Temperature exceedances were second highest in Greys Creek (no SAV).

St. Martin River

Significant improvements in both Secchi depth and K_d over time. Temperature exceedances were highest in Bishopville Prong (no SAV).

Isle of Wight

No significant changes in Secchi depth, K_d or the K_d*Secchi depth product over time in Isle of Wight. No data on temperature exceedances because no continuous monitoring.

Sinepuxent

Significant declines in the K_d*Secchi product over time observed in Sinepuxent Bay. No analyses on temperature exceedances. Analysis was not completed on temperature for this bay.

Newport

Significant improvements in Secchi depth and K_d over time. Temperature exceedances at the Newport Creek continuous monitor were above 400 hours annually from 2010-2012.

Chincoteague

Significant improvements in Secchi depth and K_d over time. Significant decreasing K_d*Secchi product over time observed in Chincoteague. Temperature exceedances at Public Landing were at or exceeded 200 hours a year above 30^oC.

Seagrass Light Model

Trends in Secchi depth, K_d and the K_d*Secchi product varied by coastal embayment. The GLM revealed significant improvements in both Secchi depth and K_d for Assawoman, St. Martin, Newport and Chincoteague. Overall, average Secchi depths in the Coastal Bays have improved by a rate of 0.01meters/year from 2003 to 2013. The greatest rates of Secchi depth improvements were in Assawoman, Newport and St. Martin (Figures 5.3.1-5.3.7). While Secchi depth has improved in recent years, current conditions still exceed the habitat threshold (0.966 m) for eelgrass in most segments (Table 5.3.1 and Chap 5.2).

Overall, the ten-year K_d median observed at the 42 Coastal Bays stations was 1.51 m^{-1}. This slightly exceeds the current light attenuation coefficient requirement (<1.5 m^{-1}) for the polyhaline portion of the Chesapeake Bay (Batiuk et al., 1992). There were significant long-term improvements in K_d in Assawoman, St. Martin, Newport and Chincoteague (Figures 5.3.1 through 5.3.7). However, median K_d values for the 10 year study period exceed the requirement in Assawoman, St. Martin and Newport (Table 5.3.1).

The Coastal Bays wide K_d*Secchi depth product has significantly declined over time (Figures 5.3.1-5.3.7). Significant decreases in the K_d*Secchi product were also observed in Chincoteague and Sinepuxent Bays. Similar decreases in K_d*Secchi depth have also been observed in the mesohaline and polyhaline portions of the Chesapeake Bay (Gallegos et al., 2011) during the same time.

We attempted to explain the changes in the Coastal Bays water clarity by examining associated changes in chlorophyll a and/or total suspended solids. However, no significant relationships between chlorophyll or total suspended solids and Secchi depth, K_d or K_d*Secchi depth were found. Gallegos et al. (2011) suggested that declines in the K_d*Secchi depth product may be accomplished by increasing the relative proportion of organic detritus in the water or increasing the tendency of particulate matter to occur in large aggregates.

Annual median K_d*Secchi products ranged between 1.06 and 1.31, with an overall median of 1.17 (Figures 5.3.1-5.3.7) while the current conversion factor for the Chesapeake Bay is K_d = 1.45/Secchi depth (Batiuk et al., 1992). The Chesapeake Bay ratio declined between 0.20 and 0.33 per year. The values calculated for the Coastal Bays are all below the standard of 1.7 (e.g. Poole and Atkins, 1929) used worldwide and the 1.44 value suggested by Holmes (1970) in turbid waters. We recommend measuring photosynthetically active radiation (PAR) at all stations using a simultaneous, two depth setup in order to calculate K_d directly. Secchi depth should be collected at a minimum if PAR measurements are not available. The use of a Secchi depth to K_d conversion ratio in the Coastal Bays should be avoided as their relationship has changed significantly over time and is lower than current standards.

Temperature Exceedance

Temperature has been shown to also be a habitat stressor to eelgrass in particular (the dominant species in the southern coastal bays). Analyses of the duration of eelgrass temperature above 30^oC showed greatest exceedances occurred during 2010-2012 (Figure 5.3.8). This may be a factor in the continued decline of seagrasses in the Maryland Coastal Bays especially in Chincoteague Bay (see Ch 5.1) which is dominated by eelgrass. In addition, high levels of ammonium may be impacting seagrass distributions (>4µM can be toxic to plants- see chapter 4.1) (van Katwijk et al. 1997; Van der Heide et al. 2008)(see Chapter 4.1 of this document).

Summary

Overall water clarity is improving in the bays, especially Chincoteague, Assawoman and Sinepuxent. The quality of light is changing in Assawoman, Chincoteague and Newport (Kd * Secchi). Multiple factors are believed to be limiting seagrass in the Maryland Coastal Bays. Direct light measurements are best for determining light available to the underwater grasses. Photosynthically available radiation (PAR), Secchi and continuous temperature measurements should continue to be collected in order to provide critical information. Recommend more frequent measurements of PAR be implemented if possible. Measurements near seagrass beds would be most beneficial (most continuous monitors are in tributaries or other areas not designated are seagrass habitat (see Chapter 5.1).

Investigation into why the K_d*Secchi depth product has significantly declined over time is needed. Similar decline in the Chesapeake Bay suggest a regional shift.

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Table 5.3.1 Trends of water clarity indicators, K_d*S, Secchi and K_d during 2003-2013 for the entire Coastal Bays and individual bay segments. Bolded results are significant. Negative Kd and positive Secchi depth slopes indicate improving clarity over time.

	1998-2013			**2003-2013**		
	Kd*S	**Secchi**	**Kd**	**Kd*S**	**Secchi**	**Kd**
All Stations	**-0.01609**	**-0.0102**	-0.00672	**-0.01182**	**0.00985**	**-0.04556**
Assawoman				0.00907	**0.02103**	**-0.04123**
Chincoteague	**-0.02004**	**-0.01413**	-0.00139	**-0.01995**	**0.00802**	**-0.04417**
Isle of Wight				0.00874	0.00626	0.01129
Newport	**-0.02114**	-0.000436	**-0.04087**	-0.00554	**0.02417**	**-0.08641**
Sinepuxent	**-0.02198**	**-0.01208**	-0.01056	**-0.01917**	0.00645	-0.01159
St. Martin				0.000172	**0.02655**	**-0.011049**

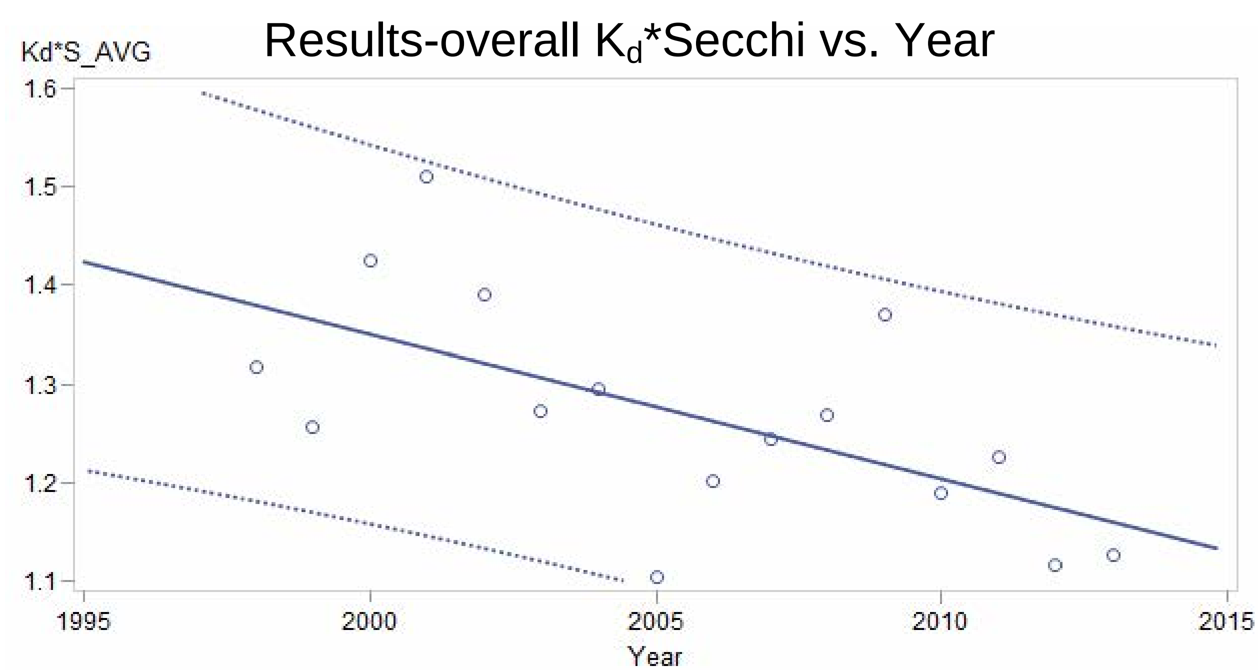

Figure 5.3.1 Maryland Coastal Bays (all bays) water clarity trend of K_d * Secchi.

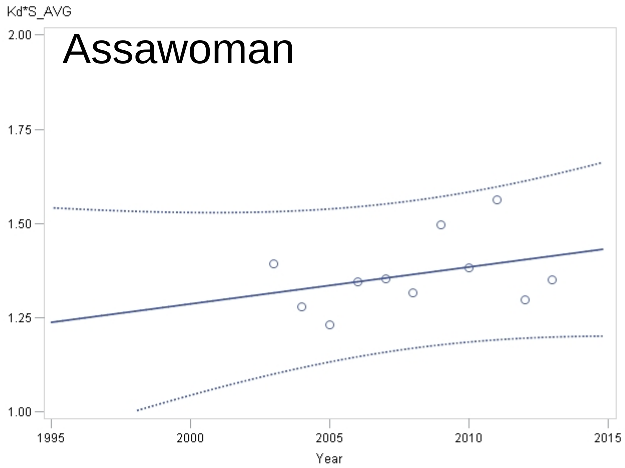

Figure 5.3.2 Assawoman Bay water clarity trend of K_d * Secchi.

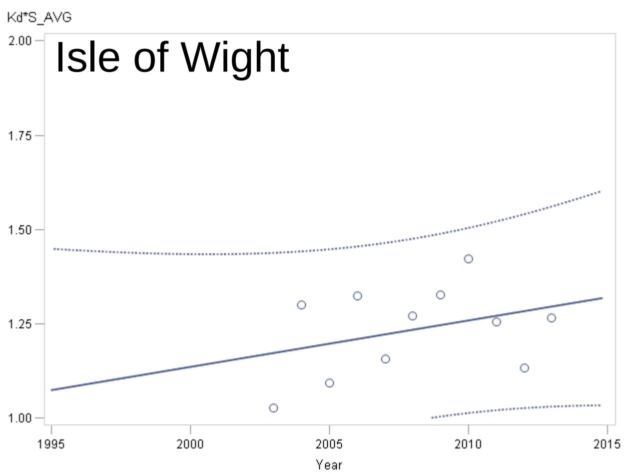

Figure 5.3.3 Isle of Wight Bay water clarity trend of K_d * Secchi.

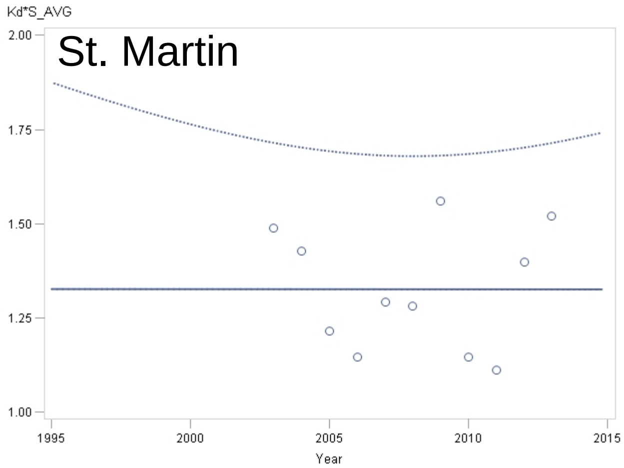

Figure 5.3.4 St. Martin River water clarity trend of K_d * Secchi.

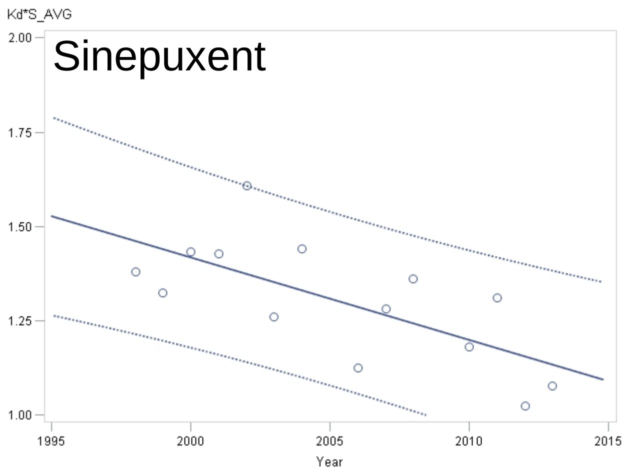

Figure 5.3.5 Sinepuxent Bay water clarity trend of K_d * Secchi.

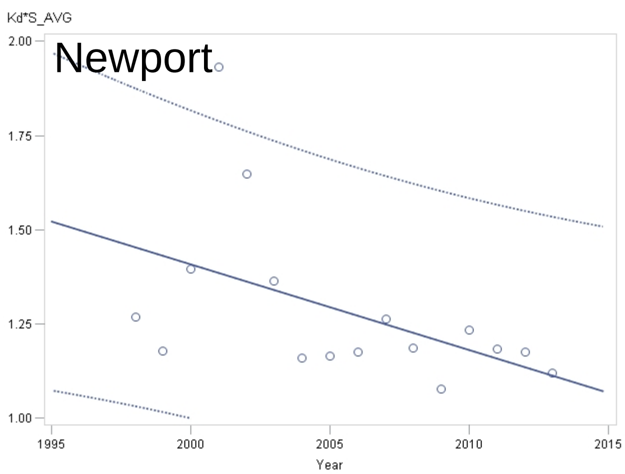

Figure 5.3.6 Newport Bay water clarity trend of K_d * Secchi.

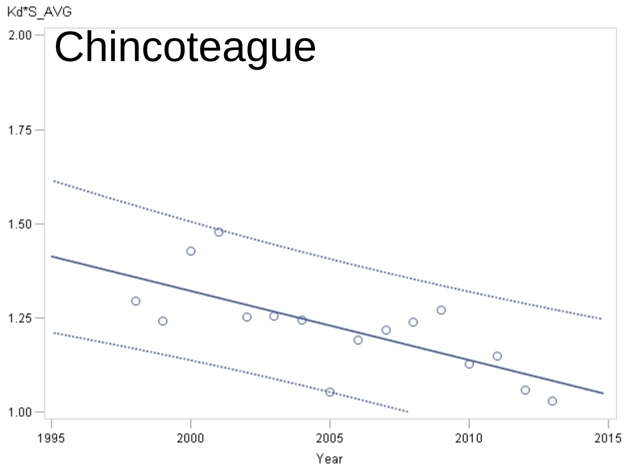

Figure 5.3.7 Chincoteague Bay water clarity trend of K_d * Secchi.

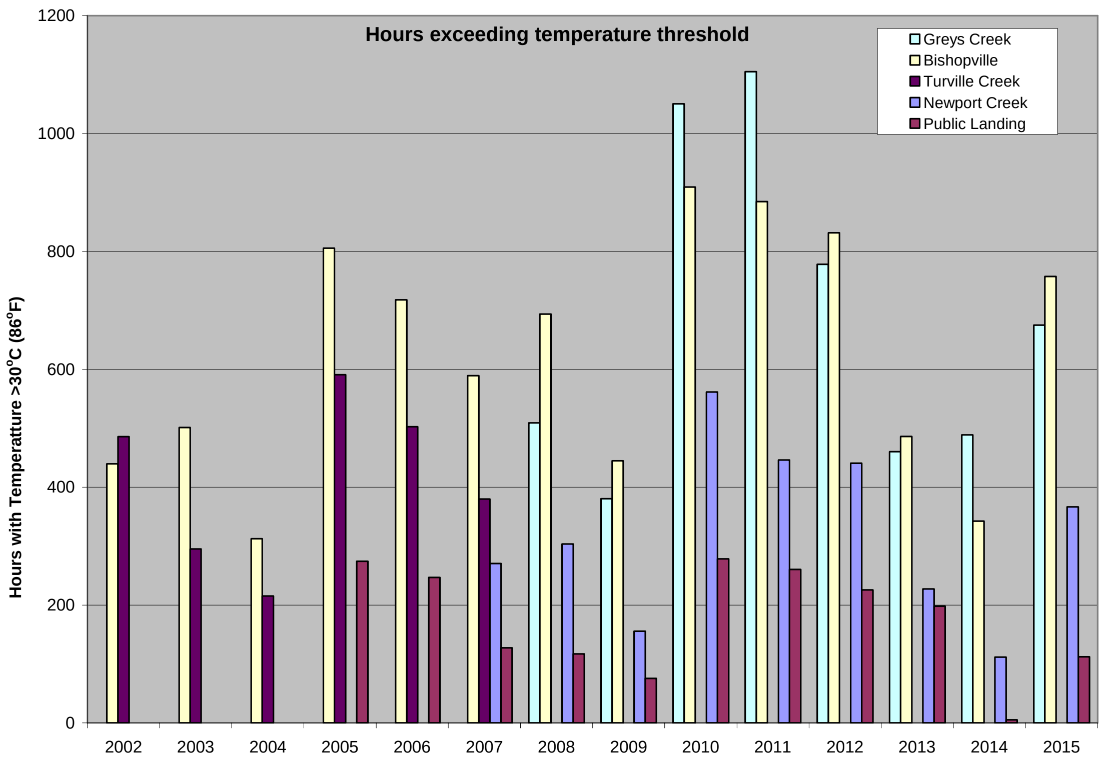

Figure 5.3.8 Duration of eelgrass temperature exceedances (>30°C or 86°F) at four continuous monitoring sites in the Coastal Bays during SAV growing season. Site NPC0012 is in Newport Bay watershed. Site XBM8828 is at Public Landing in the Chincoteague Bay watershed. Site XDM4486 is at Bishopville Prong in the St Martin watershed. Site XDN6921 is at Greys Creek in the Assawoman Bay watershed. Temperature exceedances were greatest in 2010-2012.

Chapter 5.4

Macroalgae Abundance and Distribution in the Maryland Coastal Bays

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Abstract
In order to understand potential changes in primary production in Maryland's Coastal Bays, the distribution and abundance of macroalgae were investigated in tidal locations as part of the Coastal Bays Fisheries Investigation Trawl and Beach Seine Surveys. While macroalgae abundance was highly variable, the embayments north of the Ocean City Inlet had higher abundance when compared to the southern embayments over an eight year time series (2006-2013). Most embayments were dominated by Rhodophyta, specifically *Agardhiella* and *Gracilaria,* with the exception of Chincoteague Bay, where *Polysiphonia* was the most prevelant. When environmental conditions such as water temperature, salinity or clarity were right, *Chlorophyta*, specifically *Ulva* and *Chaetomorpha*, appeared able to compete with the Rhodophytes.

Introduction
Macroalgae are a part of a healthy estuarine ecosystem, and variations in abundance, distribution, or composition of macroalgae are affected by natural environmental changes. An increase in macroalgae abundance or change in composition may be indicative of eutrophication (Doctor *et al.* 2013). It can provide cover, produce oxygen, and serve as a food source for many species in the Coastal Bays. Interestingly, macroalgae are not considered an essential habitat for fish because it is variable and ephemeral (Sogard and Able, 1991). Additionally, sea lettuce (*Ulva sp.*) produces exudates which can be toxic to winter flounder (*Pseudopleuronectes americanus*) and many invertebrates (Sogard and Able 1991).

Macroalgae abundance and composition could play an important role in fish and invertebrate composition and diversity. Several species of fishes (blennies, gobies, sticklebacks, pipefishes, and tautog (*Tautoga onitis*) have been observed using macroalgae as refuge (Olla *et al.* 1979; Stoner and Livingston, 1980; Gore *et al.* 1981, Wilson *et al*. 1990, Sogard and Able 1991, Raposa and Oviatt 2000). Macroalgae also provide habitat and foraging opportunities for several species of decapods (Wilson *et al*. 1990, Sogard and Able 1991).

Williams and Grosholz (2008) define introduced species as having been introduced outside its native range through human activities; invasive species are a subset that are likely to, or cause economic harm or ecological harm. The Mid-Atlantic Panel on Aquatic Nuisance Species lists two out of the 20 macroalgae collected in the Coastal Bays Fisheries Investigation on their Invasive Species "Of Interest" List; *Gracilaria* and *Codium*. *Gracilaria* was the dominant macroalgae in the Coastal Bays which has declined in the most recent years. *Codium* has been encountered in all but Assawoman Bay. Fortunately, *Codium* abundance (catch per unit effort, CPUE, L/ha) has remained low over the time series (Table 5.4.1). Often times, invasive species are known for steady increases in abundance, which has not been the case for *Codium* or *Gracilaria*.

Data Sets

During each Coastal Bays Fisheries Investigation (CBFI) Trawl and Beach Seine Survey, macroalgae were identified by genus and measured volumetrically (liters, L) using calibrated containers with small holes in the bottom to drain the excess water. Community composition was estimated to the nearest percent. The seine sampling was conducted at 19 fixed beach sites during June and September. The trawl sampling was conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October (Figure 5.4.3).

Analyses

To summarize macroalgae presence in the CBFI, statistical analyses were conducted on each genus and the combined total abundance from 2006 to 2013. The measure of abundance (CPUE) for the trawl and seine was mean liters per hectare (L/ha). An analysis of variance (ANOVA) was performed to determine relationships in CPUE (L/ha) by year, embayment and genus. Annual CPUE (L/ha) was compared to the time series grand mean. Macroalgae diversity was calculated by the Shannon-Weaver index.

Management Objective

CBFI has been monitoring macroalgae distribution and abundance since 2006 to provide data for potential management measures.

Results

Twenty genera of macroalgae have been collected since 2006 as part of the CBFI in Maryland's Coastal Bays (Table 5.4.1). *Rhodophyta* (Red macroalgae), *Chlorophyta* (Green macroalgae), *Phaeophyta* (Brown macroalgae) and *Xanthophyta* (Yellow-Green macroalgae) were represented in the survey collections. Rhodophytes have dominated the Coastal Bays since 1998 (McGinty *et al.,* 2002, Doctor *et al* 2013). *Ulva* and *Chaetomorpha* were the most abundant green macroalgae. *Vaucheria* were the only yellow-green genera; brown macroalgae were represented in very low abundance, most likely due to the sampling design which was focused on collecting fish and not macroalgae.

Macroalgae abundance (CPUE) across Maryland's Coastal Bays during the 2006-2013 time series has been variable for both the Trawl and Beach Seine Surveys. The Trawl Survey peak year was 2008; however, this abundance was not different than the grand mean. The years that were different than the grand mean were 2006, 2007 and 2013, of which all were below the grand mean. The Shannon Index was variable over the time series without trend (Figure 5.4.1). The macroalgae abundance (CPUE) for the Beach Seine Survey was highly variable due to the lower sample size. The years that were different than the grand mean were 2006, 2007 and 2009, of which all were below the grand mean. The Shannon Index was variable over the time series without trend (Figure 5.4.2).

Mean CPUE was higher in the embayments north of Ocean City Inlet for both Surveys. The Shannon index values were variable for the Trawl Survey, but higher in the embayments south of the inlet for the Beach Seine Survey (Figures 5.4.3; 5.4.4; 5.4.5)

Assawoman Bay

The Assawoman Bay (trawl n=21/year) has been the most productive macroalgae area in the Trawl Survey time series (Figure 5.4.4). Abundance (CPUE) was not different than the grand mean except for three years of low abundance (2006, 2007 and 2013; Figure 5.4.6). *Agardhiella* (45.6%), *Gracilaria* (38.9%) and *Ulva* (9.4%) were the prominent macroalgae in the time series. Diversity was the highest in 2013 (H = 1.29; Figure 5.4.6) due a decrease in *Agardhiella* that year. The Beach Seine Survey for Assawoman Bay (beach seine n=6/year) resulted in moderate abundance and high variability in 2008 and 2013. Four of the eight years in the time series were below the grand mean. *Agardhiella* (51.2%), *Chaetomorpha* (20.9%) and *Enteromorpha* (6.4%) were the prominent macroalgae in the time series. Diversity decreased in 2013 (H= 0.77) due to the increased abundance of *Agardhiella* (78.6%) in the littoral zone (Figure 5.4.7).

St. Martin River

The St. Martin River (trawl n=14/year) has had moderate macroalgae abundance in the Trawl Survey time series (Figure 5.4.4). Abundance (CPUE) has been below the grand mean since 2011. *Agardhiella* (44.9%), *Gracilaria* (32.7%) and *Ulva* (20.4%) were the prominent macroalgae in the time series. Diversity was low in 2013 (H = 0.82) due to the increased abundance of *Ulva* (70.6%) that year (Figure 5.4.8). The Beach Seine Survey for St. Martin River (beach seine n=2/year) resulted in high abundance and high variability in 2007 and 2010. Two of the eight years in the time series were below the grand mean. *Agardhiella* (80.2%) and *Enteromorpha* (10.1%) were the prominent macroalgae in the time series. Diversity decreased in 2013 (H= 0.33) due to the increased abundance of *Agardhiella* (92.0%) in the littoral zone (Figure 5.4.9).

Isle of Wight Bay

Isle of Wight Bay (trawl n=14/year) was the second most productive area for macroalgae the Trawl Survey time series (Figure 5.4.4). Abundance (CPUE) was below the grand mean in four of the eight years in the time series (Figure 5.4.10). *Agardhiella* (59.4%), *Gracilaria* (32.0%) and *Ulva* (5.8%) were the prominent macroalgae in the time series. Diversity increased in 2013 (H = 1.15) due to the increased abundance of *Chaetomorpha* (32.3%) that year (Figure 5.4.10). The Beach Seine Survey for Isle of Wight Bay (beach seine n=6/year) resulted in high abundance and high variability in 2010. Three of the eight years in the time series were below the grand mean. *Agardhiella* (48.3%) *Gracilaria* (14.2%) and *Cladophora* (13.5%) were the prominent macroalgae in the time series. Diversity increased in 2013 (H= 1.33) due to the increased abundance of *Chaetomorpha* (34.9%) in the littoral zone (Figure 5.4.11).

Sinepuxent Bay

Sinepuxent Bay (trawl n=21/year) had low macroalgae abundance in the Trawl Survey time series (Figure 5.4.4). Abundance (CPUE) was below the grand mean in two of the eight years in the time series (Figure 5.4.12). *Agardhiella* (41.1%), *Ulva* (28.8%) and *Gracilaria* (10.7%) were the prominent macroalgae in the time series. Diversity decreased in 2013 (H = 1.41) due to the increased abundance of *Agardhiella* (40.6%) that year (Figure 5.4.12). The Beach Seine Survey for Sinepuxent Bay (beach seine n=6/year) resulted in increasing abundance and high variability in 2013. All years in the time series were not different than the grand mean. *Agardhiella* (56.5%) and *Gracilaria* (32.6%) were the prominent macroalgae in the time series. Diversity has been low in the littoral zone (Figure 5.4.13).

<u>*Newport Bay*</u>

Newport Bay (trawl n=14/year) had low macroalgae abundance in the Trawl Survey time series (Figure 5.4.4). Abundance (CPUE) was below the grand mean in three of the eight years in the time series (Figure 5.4.14). *Agardhiella* (22.4%), *Gracilaria* (22.9%), *Polysiphonia* (19.2%) and *Ulva* (13.8%) and were the prominent macroalgae in the time series. Diversity has remained stable during the time series (Figure 5.4.14). The Beach Seine Survey for Newport Bay (beach seine n=4/year) resulted in increasing abundance and high variability over the time series. Four of eight years in the time series were below the grand mean. *Agardhiella* (47.0%), *Gracilaria* (23.7%) and *Spyridia* (13.1%) were the prominent macroalgae in the time series. Diversity has been low in the littoral zone, except in 2011 (Figure 5.4.15).

<u>*Chincoteague Bay*</u>

Chincoteague Bay (trawl n=56/year) had low macroalgae abundance in the Trawl Survey time series (Figure 5.4.16). Abundance (CPUE) was below the grand mean in two of the eight years in the time series (Figure 5.4.16). *Agardhiella* (20.4%), *Polysiphonia* (19.2%) *Chaetomorpha* (16.7%) *Vaucheria* (9.2%) and *Ulva* (7.8%) and were the prominent macroalgae in the time series. Diversity has remained stable and above the other embayments. The Beach Seine Survey for Chincoteague Bay (beach seine n=12/year) resulted in increasing abundance and high variability in 2012-2013. Six of eight years in the time series were below the grand mean. *Polysiphonia* (60.0%), *Agardhiella* (20.0%) and *Vaucheria* (9.8%) were the prominent macroalgae in the time series. Diversity has been high and variable in the littoral zone, except in 2006 (Figure 5.4.17).

Summary

Macroalgae in Maryland's Coastal Bays were investigated consistently over eight years as a supplement to the Coastal Bays Fisheries Investigation Trawl and Beach Seine Surveys. The results of this investigation show distribution and abundance of macroalgae encountered by each survey. These data are highly variable and the survey designs were not developed to perform a population assessment for macroalgae. Abundances of *Rhodophyta*, *Chlorophyta*, *Phaeophyta* and *Xanthophyta* may not be accurate because the Trawl and Beach Seine Surveys did not sample macroalgae habitat such as rocks, jetties and bulkheads where macroalgae has been observed. However those data show that *Rhodophyta* and *Chlorophyta* were present at high levels in the embayment's closest to high density human population.

Table 5.4.1 Macroalgae catch per unit effort (L/ha) from the CBFI Trawl and Beach Seine Survey, 2006-2013.

Macroalgae	Gear	2006	2007	2008	2009	2010	2011	2012	2013	Mean
Agardhs Red Weed (*Agardhiella sp.*)	Trawl	9.72	26.65	131.79	167.31	223.68	145.04	59.95	26.42	98.82
	Seine	0.07	87.12	16.73	82.80	352.41	139.06	192.66	346.91	152.22
Banded Weeds (*Ceramium sp*.)	Trawl	0.18	0.97	2.28	1.16	0.12	1.13	2.71	2.11	1.33
	Seine	5.77	2.15	0.44	0.15	0.00	4.76	0.02	1.02	1.79
Barrel Weed (*Champia sp*.)	Trawl	2.18	0.95	16.19	2.71	0.33	2.07	1.55	0.16	3.27
	Seine	0	1.12	2.75	3.11	0	0.49	1.10	2.12	1.34
Brittlewort (*Nitella sp.*)	Trawl	0	0	0	0	0	0	0	0	0
	Seine	0	0	0	0.32	0	0	0	0	0.04
Brown Bubble Algae (*Colpomenia sp.*)	Trawl	0	0	0	0	0	0	0.04	0.01	0.01
	Seine	0	0	0	0	0	0	0	0	0
Common Southern Kelp (*Laminaria sp.*)	Trawl	0	0	0	0	0	0.67	0.01	0.04	0.09
	Seine	0	0	0	0	0	0	0	0	0
Ectocarpus Genus (*Ectocarpus sp*.)	Trawl	0	0	0	0	0	0	0	0	0
	Seine	0	0	1.67	0	0	0	0	0	0.21
Graceful Red Weed (*Gracilaria sp.*)	Trawl	37.80	26.35	175.94	25.55	41.34	202.37	129.93	0.52	79.98
	Seine	66.25	33.41	81.17	17.45	84.02	15.32	0.67	1.24	37.44
Green Fleece (*Codium fragile*)	Trawl	0	0.21	0.75	0.67	0.09	0.21	1.54	0.40	0.49
	Seine	2.81	0	0	1.37	0	6.45	16.11	5.48	4.03
Green Hair Algae (*Chaetomorpha sp.*)	Trawl	0.91	1.17	4.38	26.12	14.95	2.66	0.06	10.20	7.56
	Seine	4.17	0.00	88.64	6.61	1.12	15.40	0.31	49.69	20.74
Green Sea Fern (*Bryopsis sp.*)	Trawl	0	0	0	0	0	0.01	0	0.06	0.01
	Seine	0	0	0	0.58	0	0	0	0.62	0.15
Green Tufted Seaweed (*Cladophora sp*.)	Trawl	0.79	0.06	1.06	0.00	0.00	0.52	8.32	0.54	1.41
	Seine	16.26	0.27	81.64	0.04	59.94	1.61	1.07	0.77	20.20
Hairy Basket Weed (*Spyridia sp.*)	Trawl	0	0	0	0.35	0.19	0.24	2.93	0.49	0.52
	Seine	0	0	0	0.20	0.83	16.90	1.03	18.36	4.66
Hollow Green Weed (*Enteromorpha sp.*)	Trawl	0.03	0.37	2.50	1.08	1.09	1.36	5.05	0.47	1.49
	Seine	10.43	0.02	34.60	13.21	31.36	10.80	0.66	20.42	15.19
Hooked Red Weed (*Hypnea sp.*)	Trawl	0	0	0.04	0	0	0.08	0.03	0	0.02
	Seine	0	0	2.00	0	0	0	0	0	0.25
Rockweed (*Fucus sp.*)	Trawl	0.01	0.01	0	0.15	0.10	0	0	0	0.03
	Seine	0.21	0.01	1.01	0	0	0	0	0	0.15
Sea Lettuce (*Ulva sp.*)	Trawl	4.50	11.39	43.12	43.96	17.49	17.58	7.72	12.67	19.80
	Seine	2.01	8.81	10.04	2.21	27.81	4.74	12.28	23.28	11.40
Sour Weeds (*Desmarestia sp.*)	Trawl	0	0	9.81	0	0	2.41	0.03	0.03	1.54
	Seine	0	0	1.45	0	0	0.03	0.01	0	0.19
Tubed Weeds (*Polysiphonia sp.*)	Trawl	0.10	14.98	0.01	0.70	1.79	10.45	31.13	12.23	8.92
	Seine	1.19	0.78	0.54	0.03	0.20	1.41	46.66	115.11	20.74
Water Felt (*Vaucheria sp*.)	Trawl	0	0	0.59	10.09	0.71	1.59	2.75	6.11	2.73
	Seine	0	0	0.60	2.08	6.95	11.60	8.94	19.64	6.22

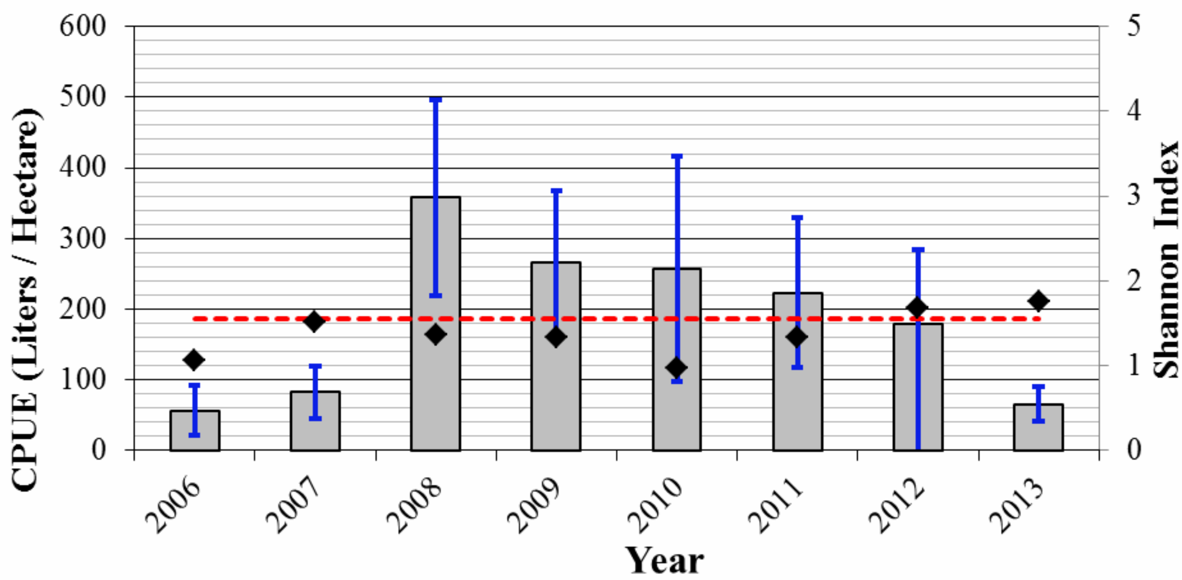

Figure 5.4.1 Coastal Bays Fisheries Investigation Trawl Survey Index of macroalgae relative abundance (CPUE; L/ha) in ALL BAYS with 95% confidence intervals (2006-2013). Black diamond represents the 2006-2013 time series Shannon index of diversity.

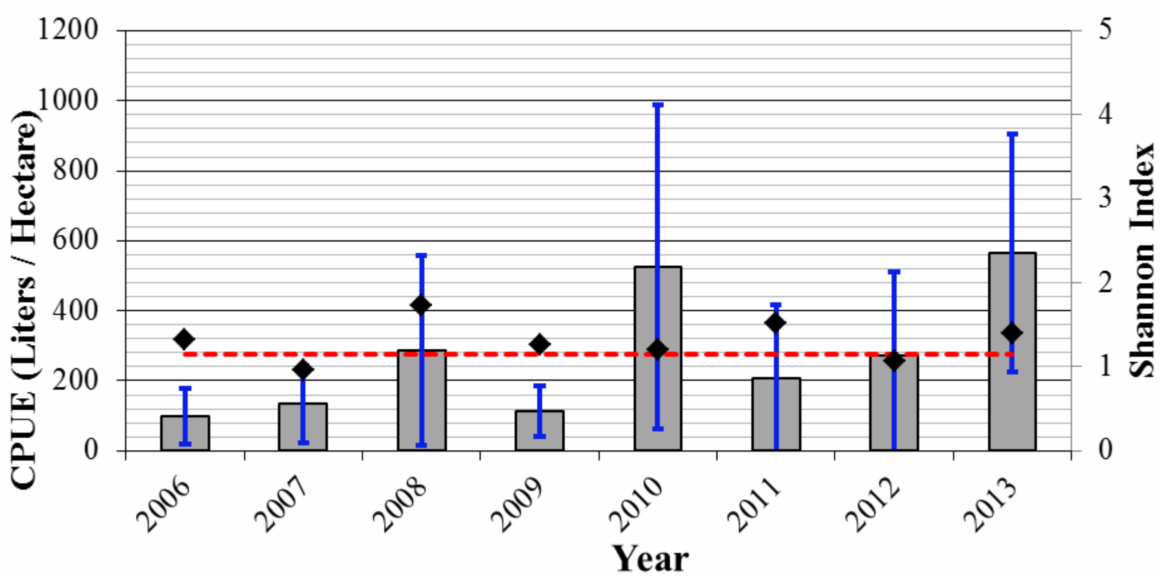

Figure 5.4.2 Coastal Bays Beach Seine Survey index of macroalgae relative abundance (CPUE; L/ha) in ALL BAYS with 95% confidence intervals (2006-2013). Black diamond represents the 2006-2013 time series Shannon index of diversity.

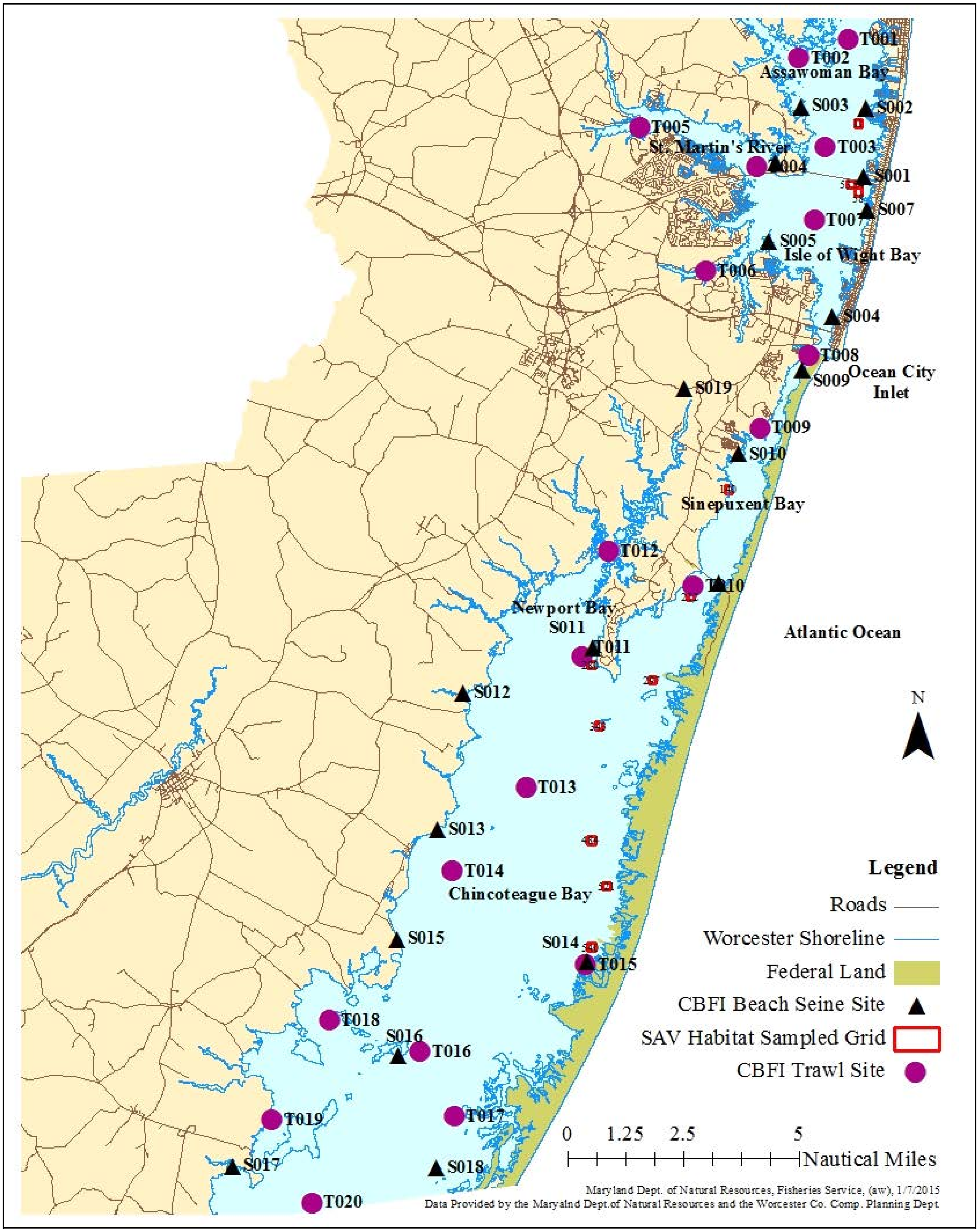

Figure 5.4.3 Coastal Bay Fisheries Investigation Trawl and Beach Seine Survey sample sites (2013).

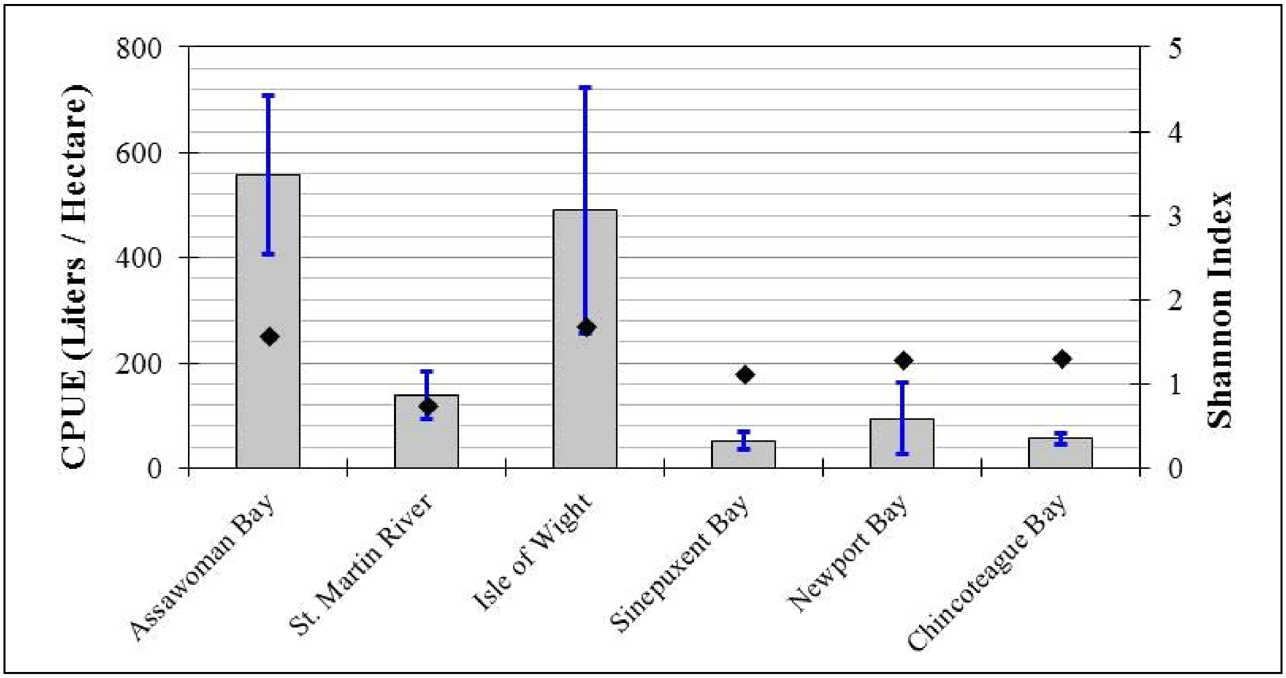

Figure 5.4.4 Coastal Bays Fisheries Investigation Trawl Survey index of macroalgae relative abundance (CPUE; L/ha) by sub-watershed with 95% confidence intervals (2006-2013). Black diamond represents the 2006-2013 time series Shannon index of diversity.

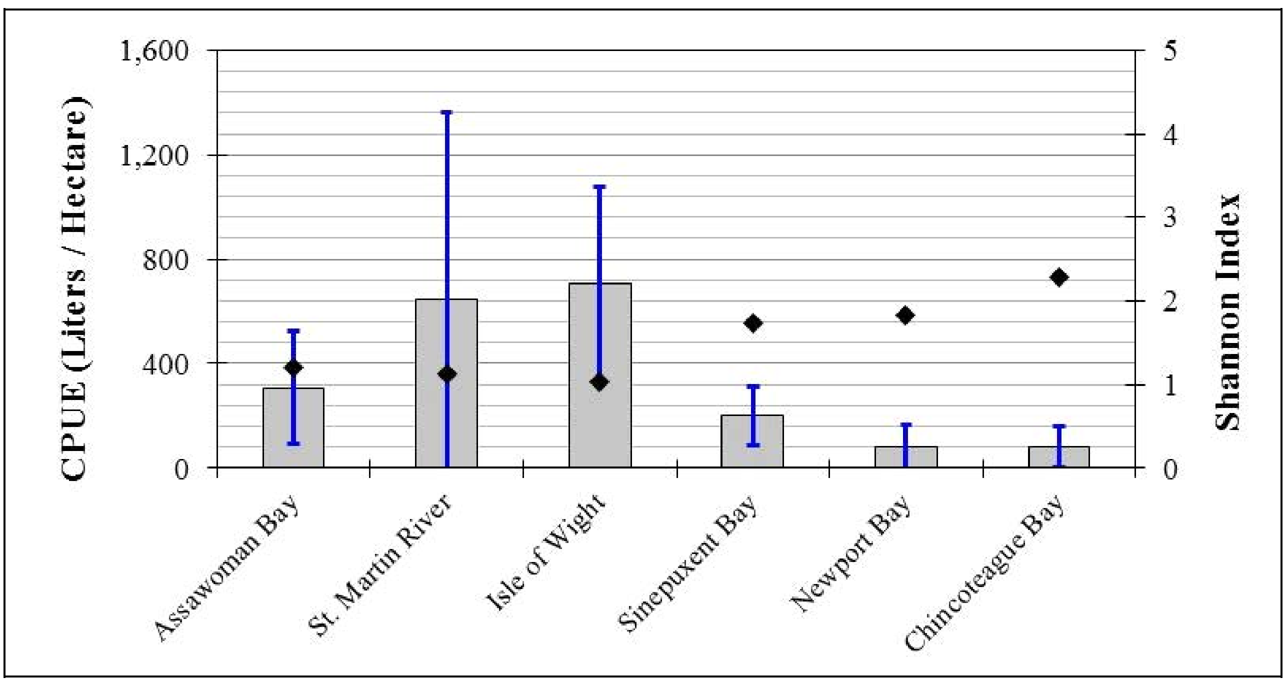

Figure 5.4.5 Coastal Bays Fisheries Investigation Beach Seine Survey index of macroalgae relative abundance (CPUE; L/ha) by sub-watershed with 95% confidence intervals (2006-2013). Black diamond represents the 2006-2013 time series Shannon index of diversity.

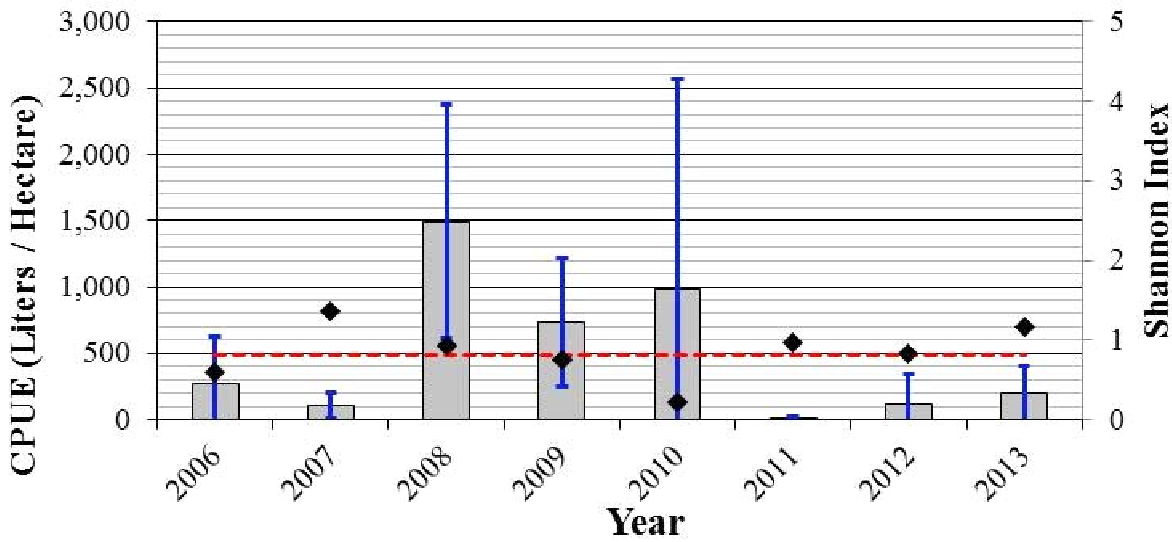

Figure 5.4.6 Coastal Bays Fisheries Investigation Trawl Survey index of Assawoman Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=21/year). Black diamond represents the Shannon index of diversity.

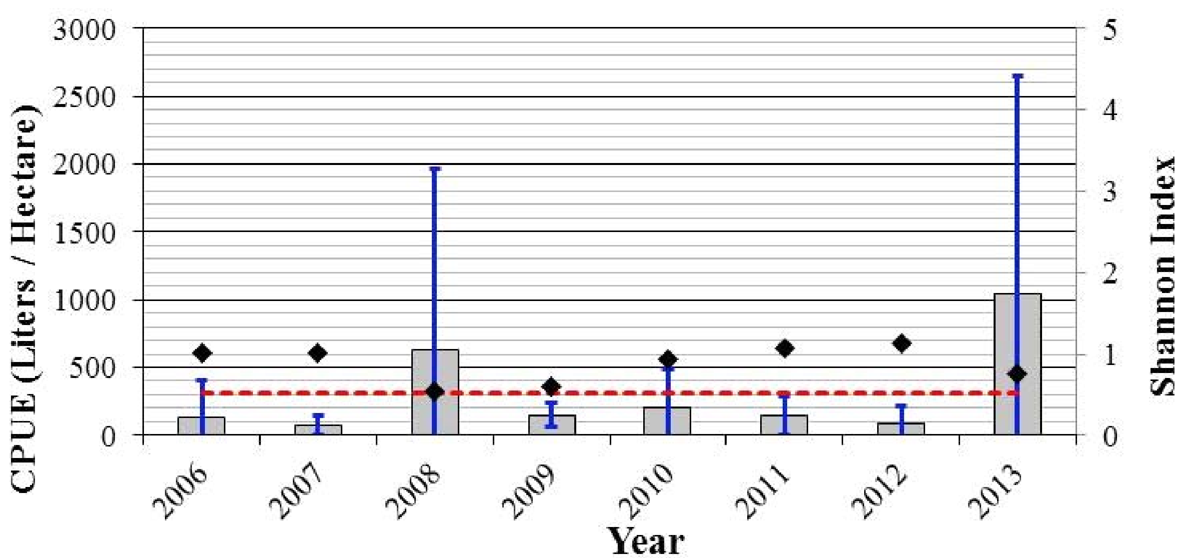

Figure 5.4.7 Coastal Bays Fisheries Investigation Beach Seine Survey index of Assawoman Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013).

Dotted line represents the 2006-2013 time series CPUE grand mean, (n=6/year). Black diamond represents the Shannon index of diversity.

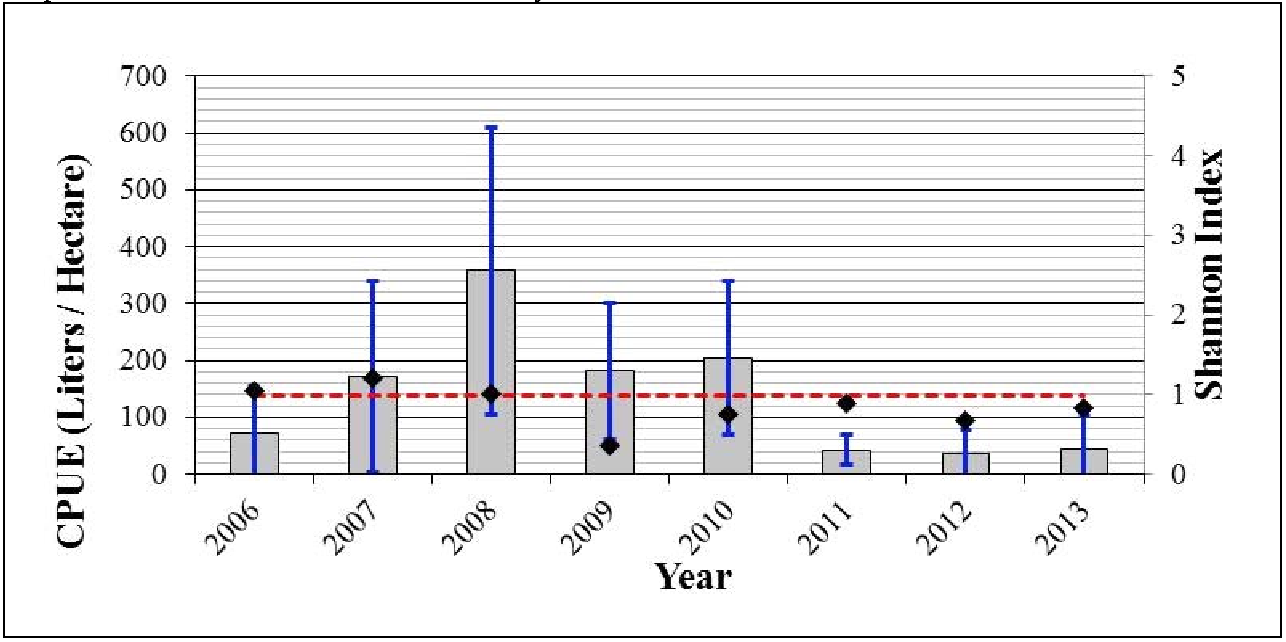

Figure 5.4.8 Coastal Bays Fisheries Investigation Trawl Survey index of St. Martin River macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=14/year). Black diamond represents the Shannon index of diversity.

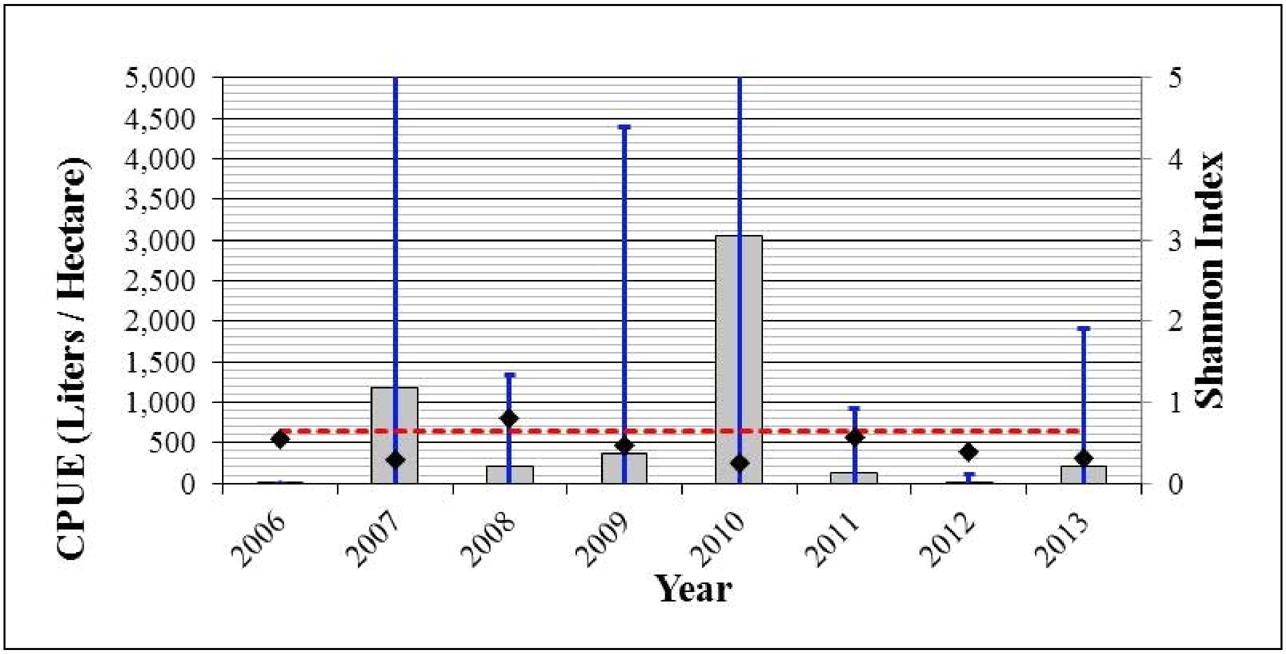

Figure 5.4.9 Coastal Bays Fisheries Investigation Beach Seine Survey index of St. Martin River macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=2/year). Black diamond represents the Shannon index of diversity

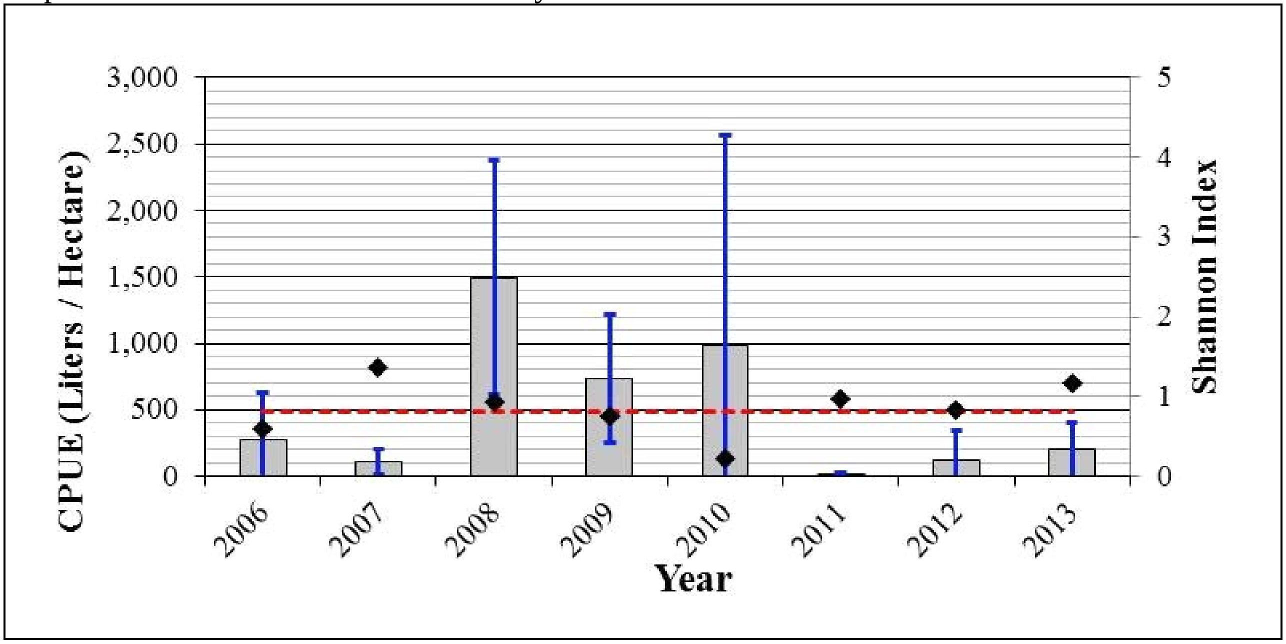

Figure 5.4.10 Coastal Bays Fisheries Investigation Trawl Survey index of Isle of Wight Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=14/year). Black diamond represents the Shannon index of diversity.

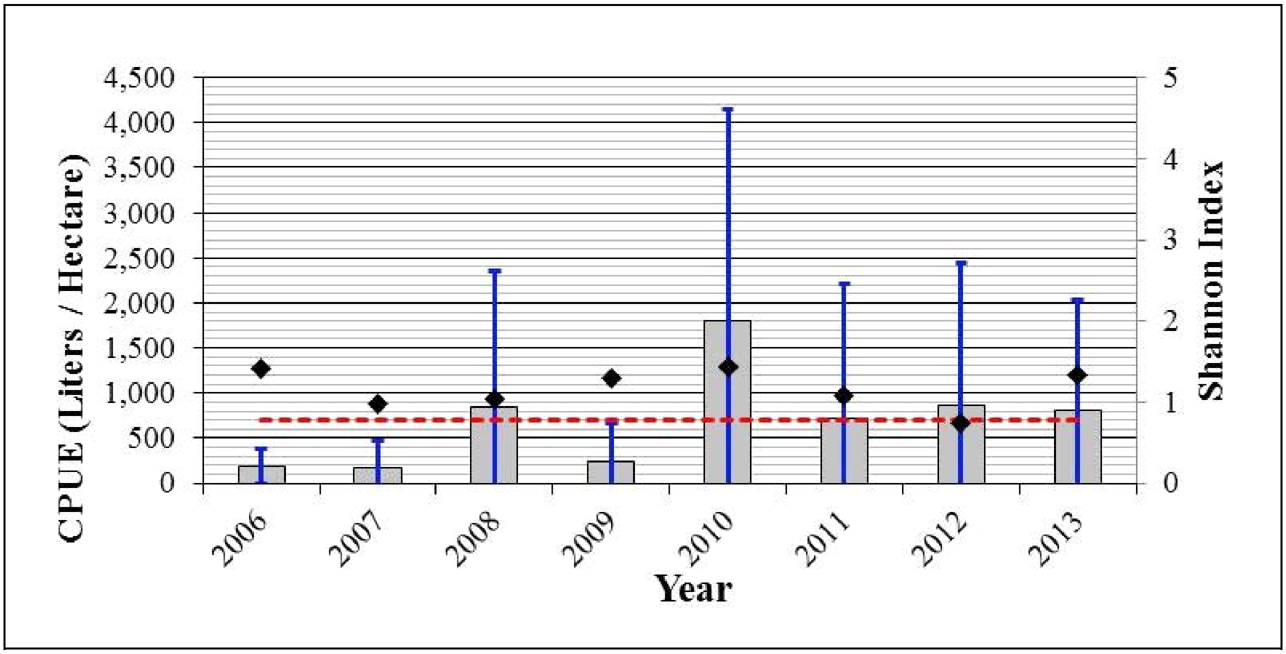

Figure 5.4.11 Coastal Bays Fisheries Investigation Bay Beach Seine Survey index of Isle of Wight macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=4/year). Black diamond represents the Shannon index of diversity.

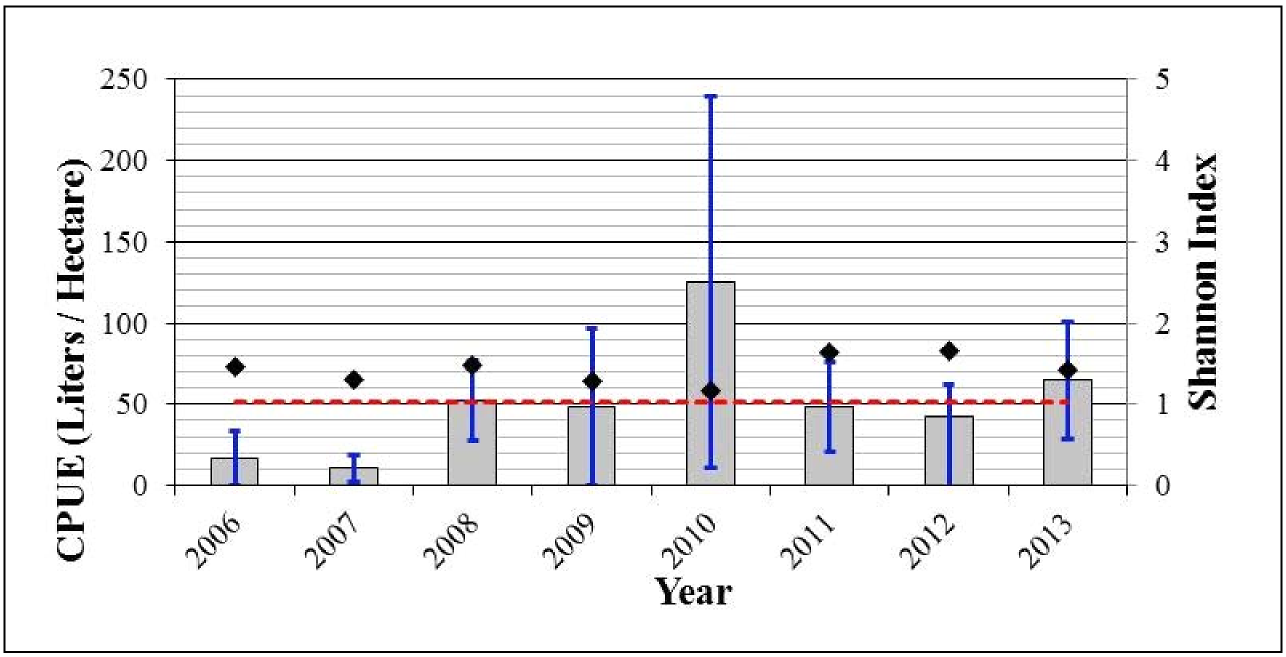

Figure 5.4.12 Coastal Bays Fisheries Investigation Trawl Survey index of Sinepuxent Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=21/year). Black diamond represents the Shannon index of diversity.

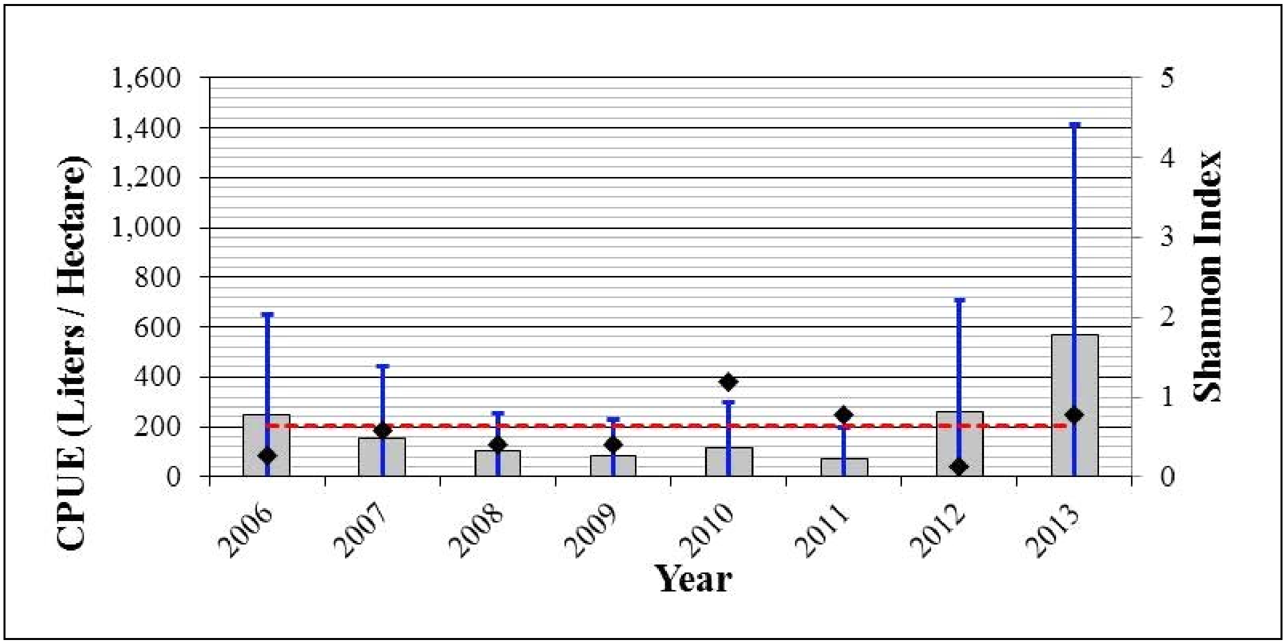

Figure 5.4.13 Coastal Bays Fisheries Investigation Beach Seine Survey index of Sinepuxent Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=6/year). Black diamond represents the Shannon index of diversity.

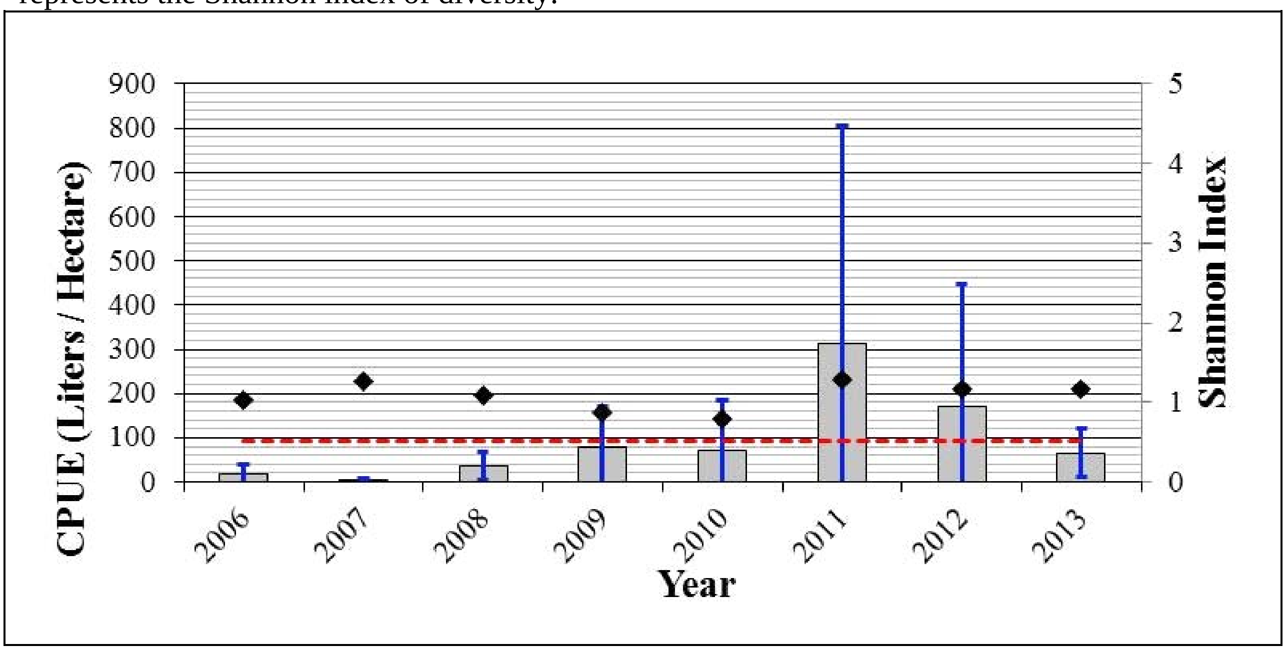

Figure 5.4.14 Coastal Bays Fisheries Investigation Trawl Survey index of relative Newport Bay macroalgae abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=14/year). Black diamond represents the Shannon index of diversity.

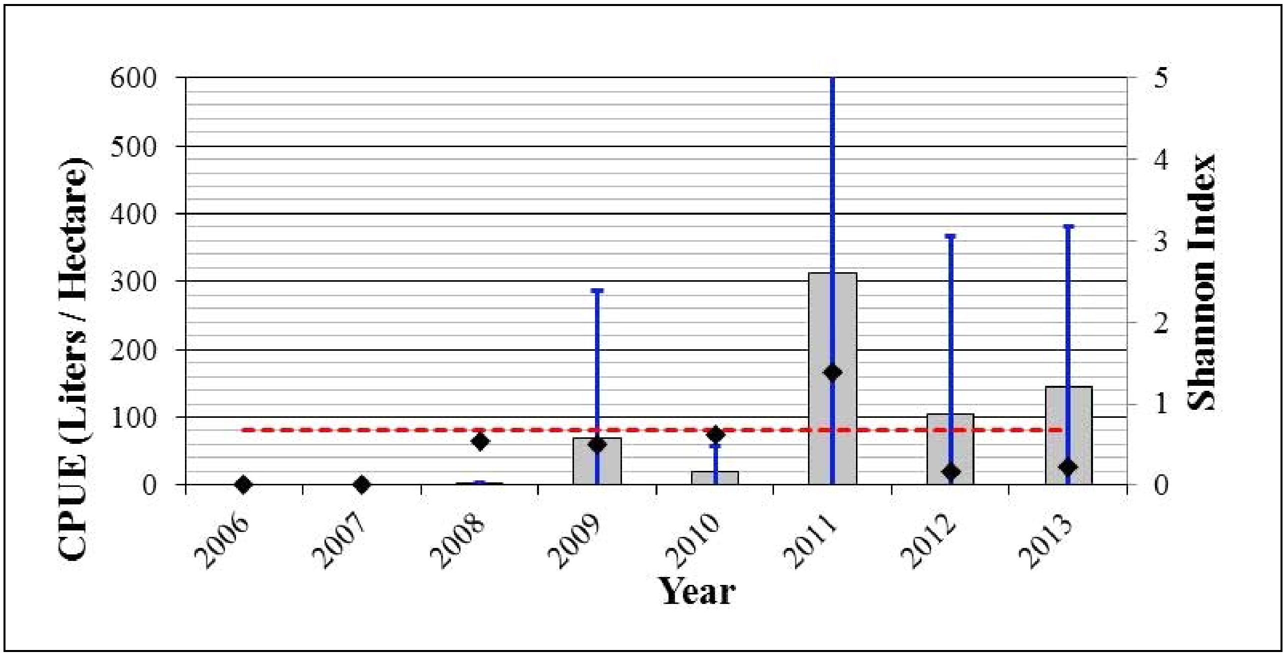

Figure 5.4.15 Coastal Bays Fisheries Investigation Beach Seine Survey index of Newport Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=4/year). Black diamond represents the Shannon index of diversity.

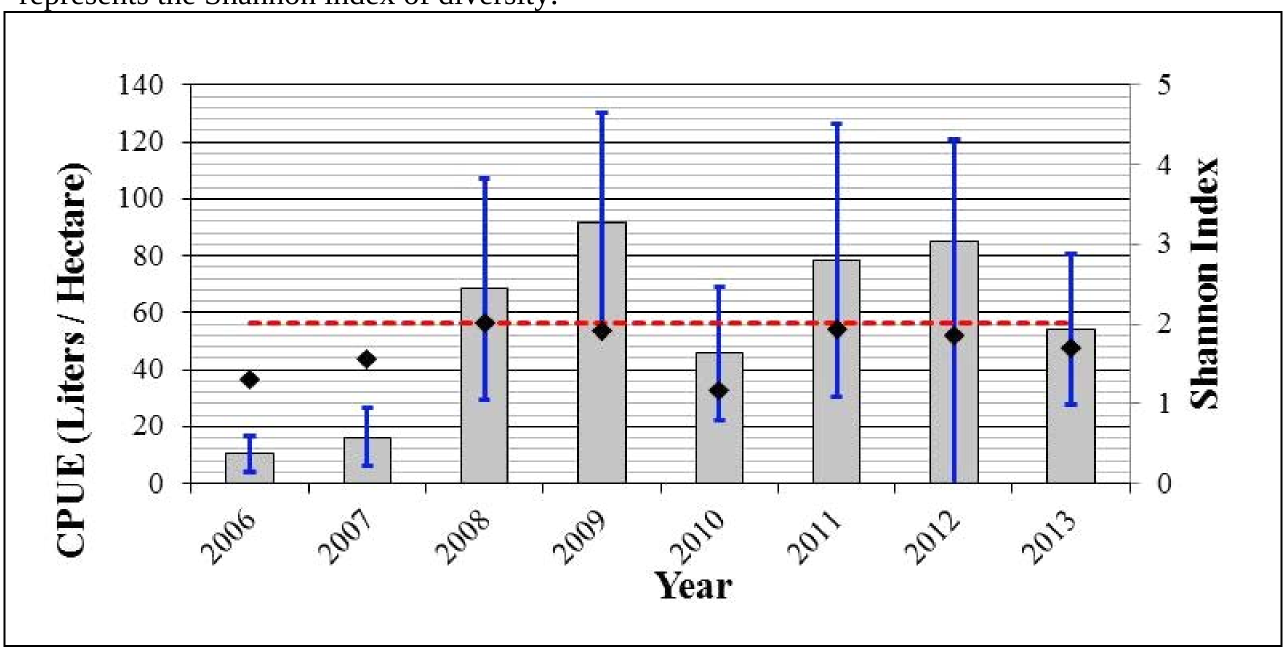

Figure 5.4.16. Coastal Bays Fisheries Investigation Trawl Survey index of Chincoteague Bay macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Dotted line represents the 2006-2013 time series CPUE grand mean, (n=56/year). Black diamond represents the Shannon index of diversity.

Figure 5.4.17 Coastal Bays Fisheries Investigation Beach Seine Survey index Chincoteague Bay of macroalgae relative abundance (CPUE; L/ha) with 95% confidence intervals (2006-2013). Red line represents the 2006-2013 time series CPUE grand mean, (n=12/year). Black diamond represents the Shannon index of diversity.

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Chapter 6.1

Abundance and Frequency of Occurrence of Brown Tide, *Aureococcus anophagefferens*, in Maryland's Coastal Bays

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Abstract
Aureococcus anophagefferens, the micro-organism that causes brown tide, was first identified in the United States in 1987 and was discovered in Maryland in 1998, though recent research indicates that it was present before then. Brown tide blooms have been categorized based on their potential impacts to living resources [categories 1 (lowest), 2, and 3 (highest)]. Brown tide is a problem in the Coastal Bays; annually since 1999, at least one of the bay segments has experienced a category 3 bloom.

Introduction

Brown tide**,** *Aureococcus anophagefferens***,** blooms can have serious impacts on shellfish populations (scallops, hard clams and mussels) and seagrasses. Brown tides are known from their occurrence in the northeastern United States and western Africa. *A. anophagefferens* was first identified in the United States in Narragansett Bay, Rhode Island in 1987 and discovered in Maryland in 1998 (Gastrich and Wazniak, 2000). Data collected by the National Park Service (NPS) showed *A. anophagefferens* was present in the Coastal Bays since at least 1993 based on the presence of a pigment unique to this algal species detected in archived NPS samples (Trice et al., 2004). No samples were available for the period prior to 1993. Maryland is currently the southern extent for *A. anophagefferens* in the United States.

Monitoring

Since 1999, the Maryland Department of Natural Resources' (DNR) Brown Tide (BT) monitoring program has been conducted with a fixed station network of 15 stations throughout the Coastal Bays. Results have revealed that blooms tend to occur in late spring and early summer (May-July). Brown tide has been found in all Coastal Bays segments; however, an area in the Southern Bays from Newport Bay to Public Landing across to Tingles Island consistently has the highest levels. Scientists classify Brown Tide blooms similar to hurricanes Category 1, 2 and 3 (Gastrich and Wazniak, 2000) with 3 having the most serious environmental impacts (Table 6.1.1).

Table 6.1.1 Brown tide categories and potential environmental impacts.

Category	*Aureococcus* concentration	Potential Ecosystem Impacts
1	<35,000 cells*ml^{-1}	No observed impacts
2	35,000 to < 200,000 cells*ml^{-1}	• Reduction in growth of juvenile hard clams, (*Mercenaria mercenaria*). • Reduced feeding rates in adult hard clams; • Growth reduction in mussels (*Mytilus edulis*) and bay scallops (*Argopecten irradians*).
3	≥ 200,000 cells*ml^{-1}	• Water becomes discolored yellow-brown; • Feeding rates of mussels severely reduced; • Recruitment failures of bay scallops; • No significant growth of juvenile hard clams; • Negative impacts to eelgrass due to algal shading; • Copepod production reduced and negative impacts to protozoa.

Status of brown tide bloom activity in the Coastal Bays

Bloom intensity and distribution varied annually across the Coastal Bays. The 3-year status of max blooms is presented as a summary (Figure 6.1.1). To learn more about the annual and interannual variability, please visit: http://dnr..maryland.gov/coastalbays/bt_results.html.

Table 6.1.2 Flow at USGS Gage on Birch Branch- Annual Mean Discharge (cubic feet per second) by water year.

USGS	148471320	2001	5.87
USGS	148471320	2002	1.84*
USGS	148471320	2003	15.4
USGS	148471320	2004	12.2
USGS	148471320	2005	9.93
USGS	148471320	2006	4.4
USGS	148471320	2007	8.41
USGS	148471320	2008	4.08
USGS	148471320	2009	8.65
USGS	148471320	2010	19.2
USGS	148471320	2011	4.71
USGS	148471320	2012	6.34
USGS	148471320	2013	16.3

Table Data Source:
http://waterdata.usgs.gov/md/nwis/annual/?referred_module=sw&site_no=0148471320&por_0148471320_2=15

56908,00060,2,2000,2016&year_type=W&format=html_table&date_format=YYYY-MM-DD&rdb_compression=file&submitted_form=parameter_selection_list

2007 The highest concentrations over the 12 year period were observed at Public Landing, Trappe, and Newport Bay. The bloom continued at many southern sites during May and June. The conditions were generally dry based on the RAWS weather stations. However, no bloom was recorded in the northern bays. Average flow at Birch Branch on the St Martin River. (Figure 6.1.6)

2008 Public Landing and Tingles Island sites were the only two to see a count above the category 3 threshold in late May. Category 2 blooms were seen in the Northern bay sites as well as Trappe, Newport and Public Landing. (Figure 6.1.7)

2009 No blooms occurred in the northern bays. There was a Category 3 bloom that lasted a month at Public Landing and Tingles Island sites. (Figure 6.1.8)

2010 No blooms occurred in the northern bays. Wettest year observed at Birch Branch (Table 6.1.1). There was a Category 3 bloom that covered Green Point, Public Landing, and Tingles Island (lesser bloom at Taylors Landing) in late May/early June. (Figure 6.1.9)

2011 The northern bays had a category 2 bloom in Isle of Wight Bay near Rt. 90 bridge (site XDN3445) in May reaching cell counts of over 120,000; while the southern bays had widespread blooms in June with lower concentrations than the Isle of Wight bloom. (Figure 6.1.10)

2012 Early June three sites in the southern bays (Newport, Public Landing and Tingles Island) had category 3 blooms but did not last long due to weather and one site in the northern bays exceeded 200,000 cells/ml (Manklin Creek in late May). (Figure 6.1.11)

2013 No significant blooms were found. (Figure 6.1.12)

References

Gastrich, M.D. and C.E. Wazniak. 2002. A brown tide bloom index based on the potential harmful effects of the brown tide alga, *Aureococcus anophagefferens*. Aquatic Ecosystem Health and Management 5: 435-441.

Trice, T.M., P.M. Glibert, C. Lea, and L. Van Heukelem. In press. HPLC pigment records provide evidence of past blooms of *Aureococcus anophagefferens* in the coastal bays of Maryland and Virginia, USA. Harmful Algae.

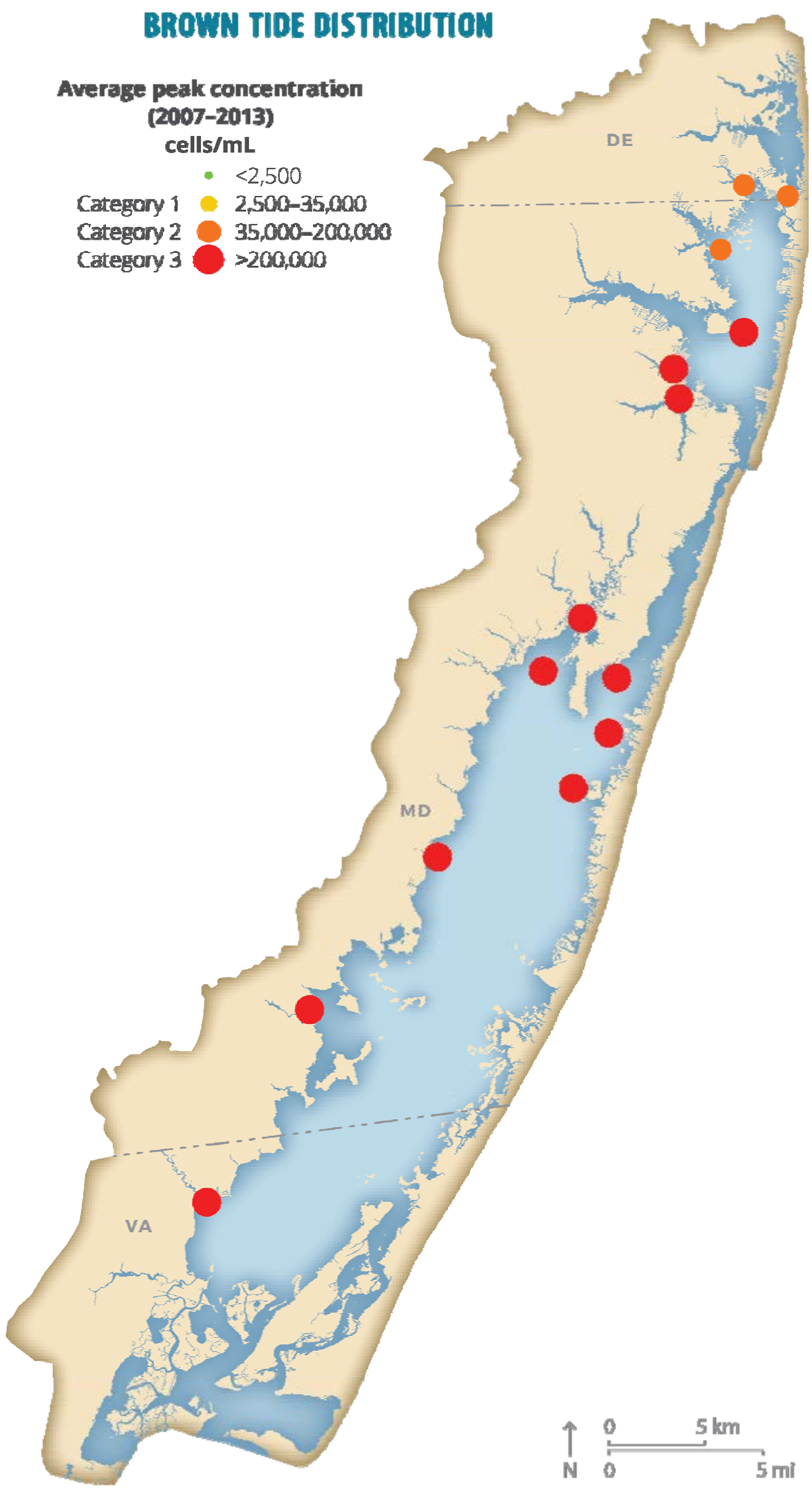

Figure 6.1.1 Average peak concentration of brown tide cells at fourteen Maryland Coastal Bays station between 2007and 2013.

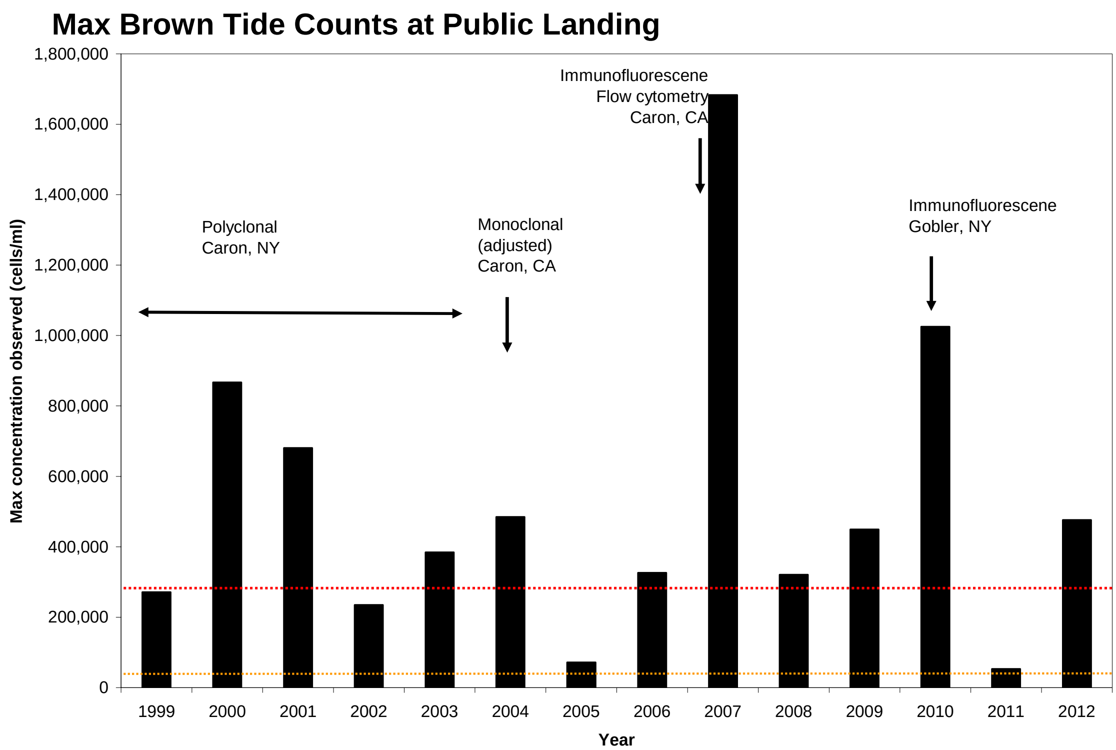

Figure 6.1.2 Maximum annual *Aureococcus* concentrations at Public Landing (1999-2012). Enumeration methods used for counts are also noted.

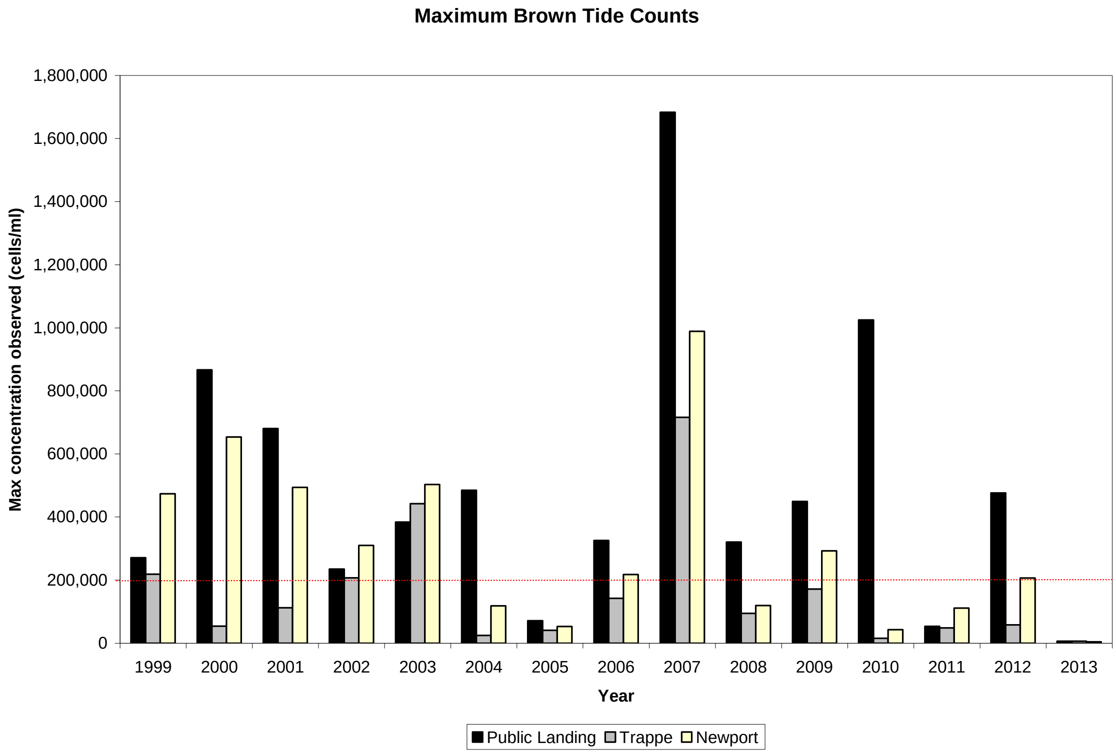

Figure 6.1.3 Maximum *Aureococcus* cell counts at three stations (Public landing, Trappe Creek and Newport Bay (1999-2013)

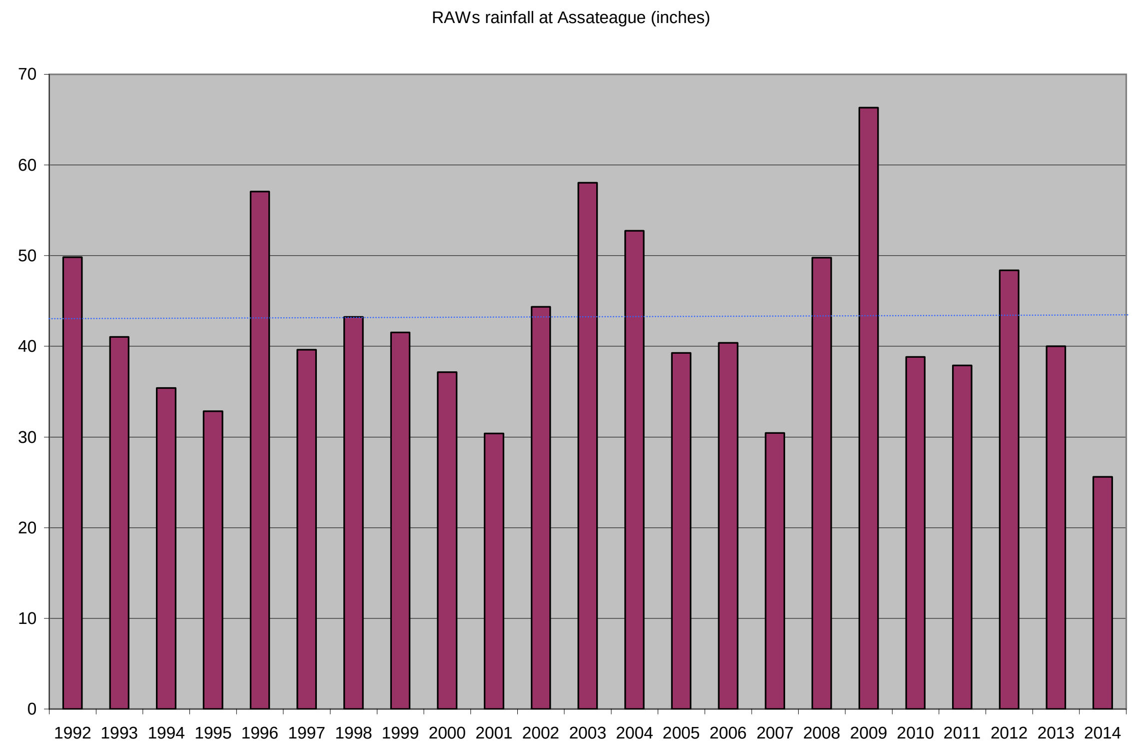

Figure 6.1.4 Annual rainfall at Assateague Island Rainfall at Remote Automated Weather Station (RAWS) rain gage in inches per year (1992-2014).

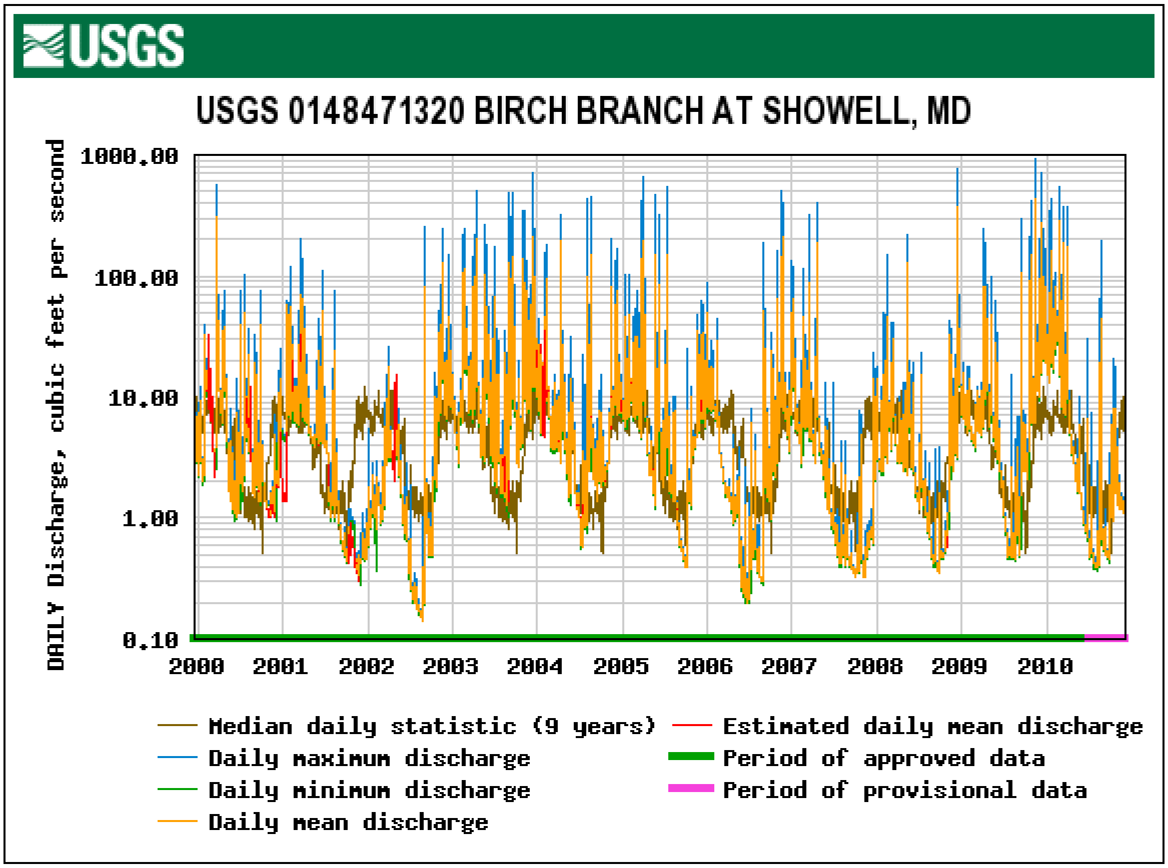

Figure 6.1.5 Daily river discharge at the USGS gage on Birch Branch (cubic feet per second) 2000-2010.

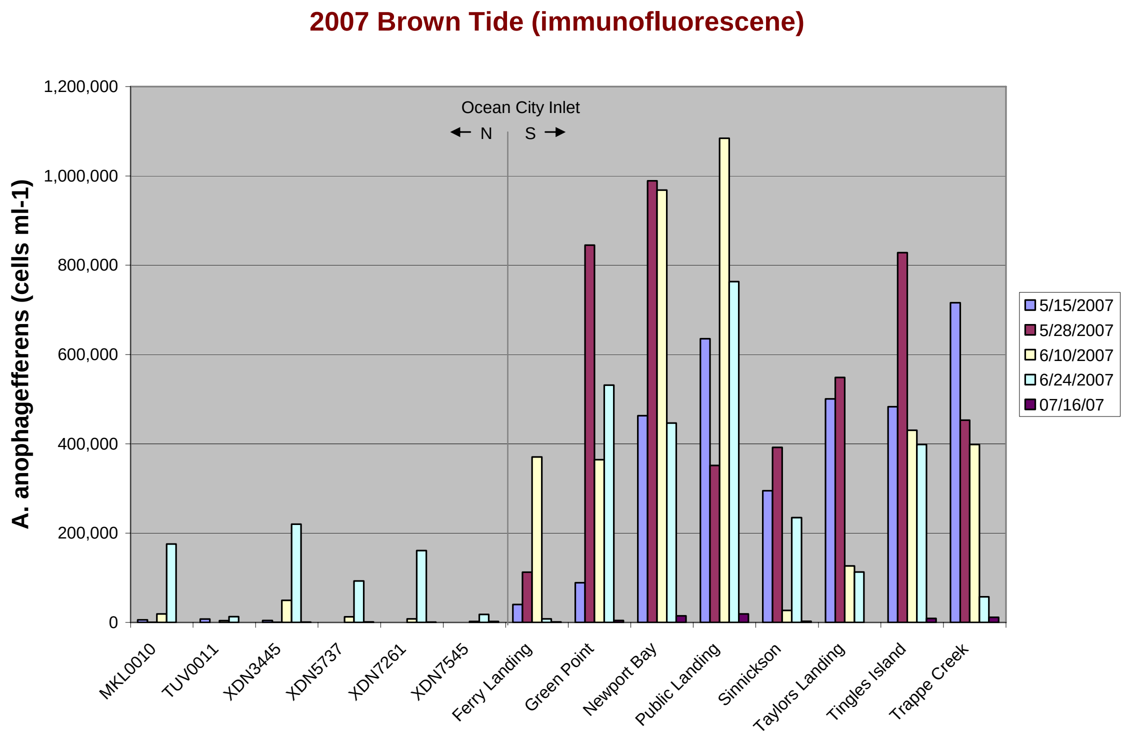

Figure 6.1.6 2007 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

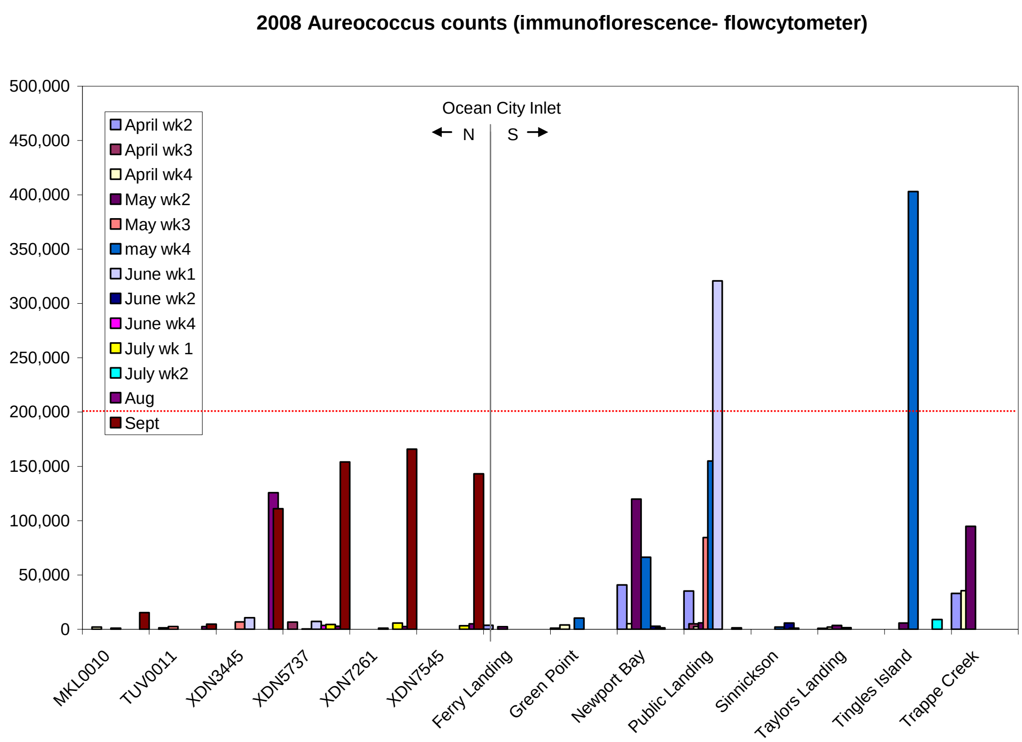

Figure 6.1.7 2008 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

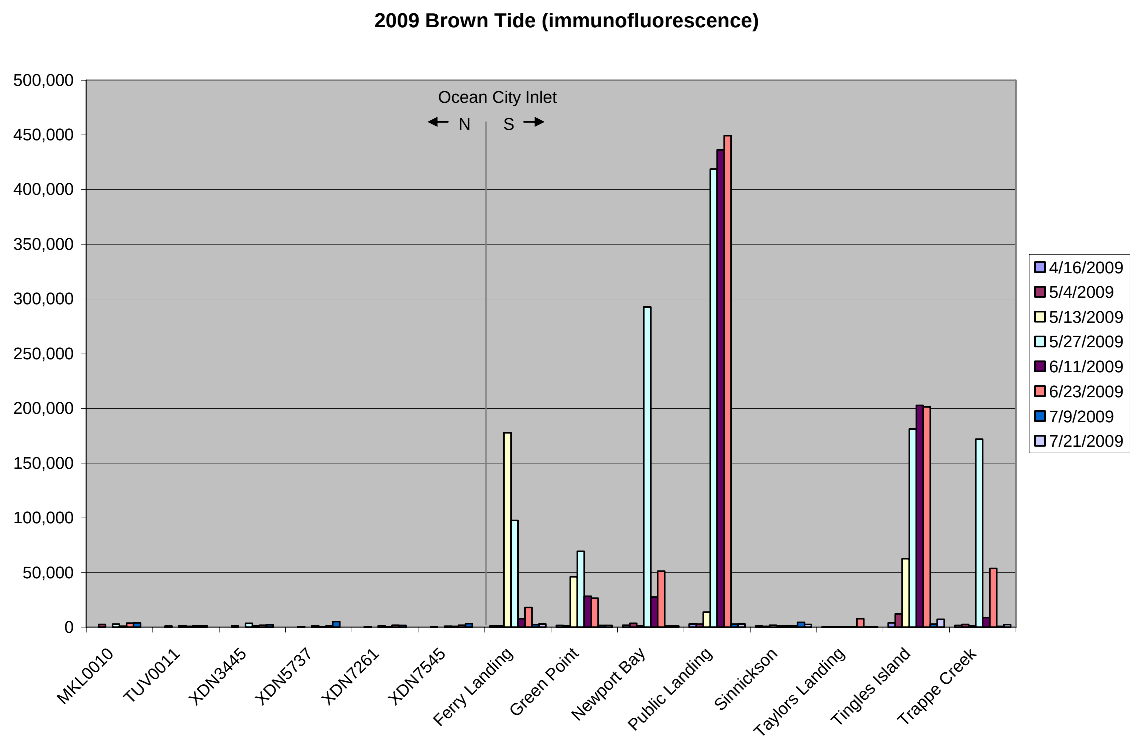

Figure 6.1.8 2009 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

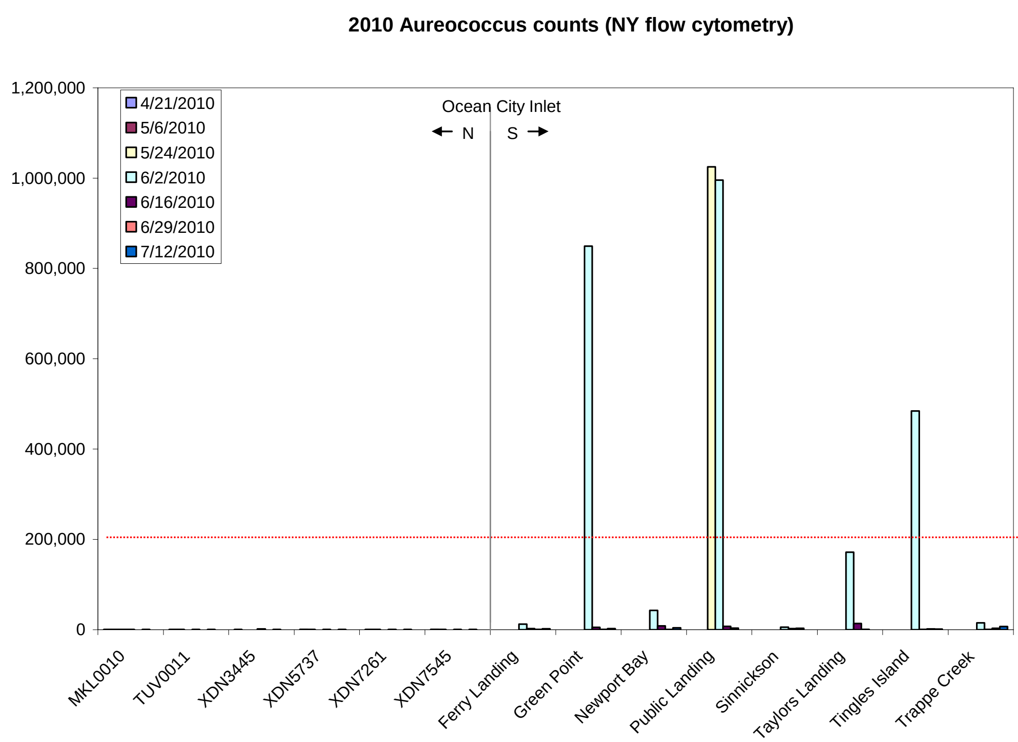

Figure 6.1.9 2010 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

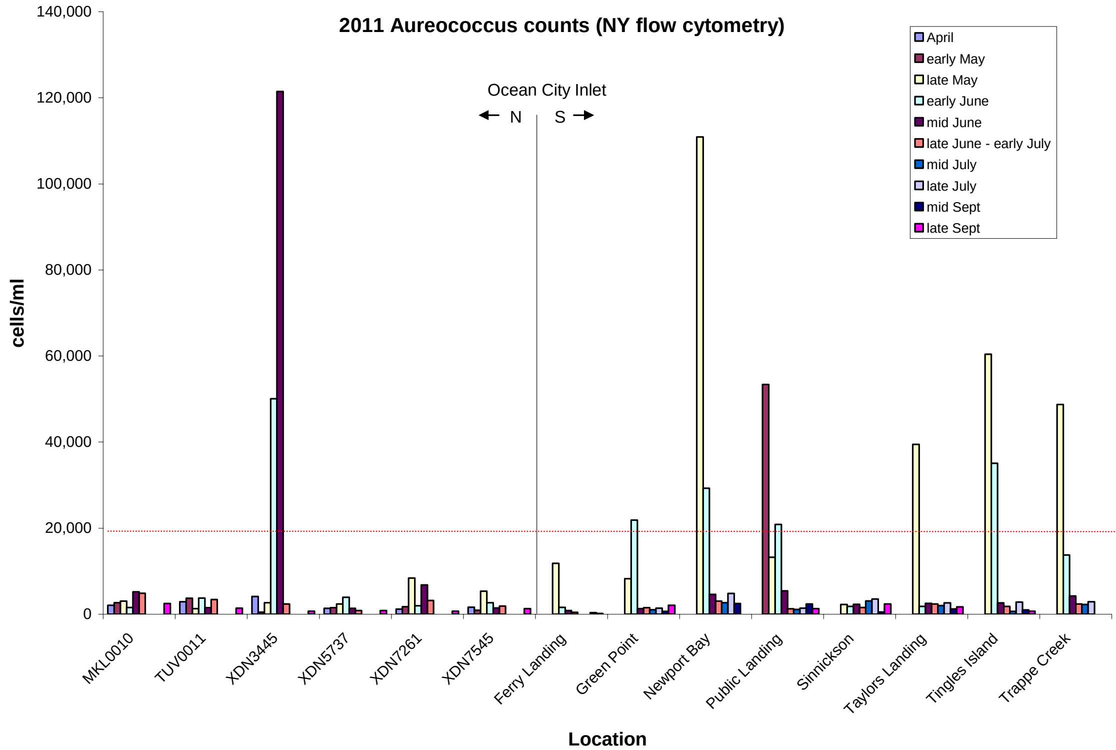

Figure 6.1.10 2011 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

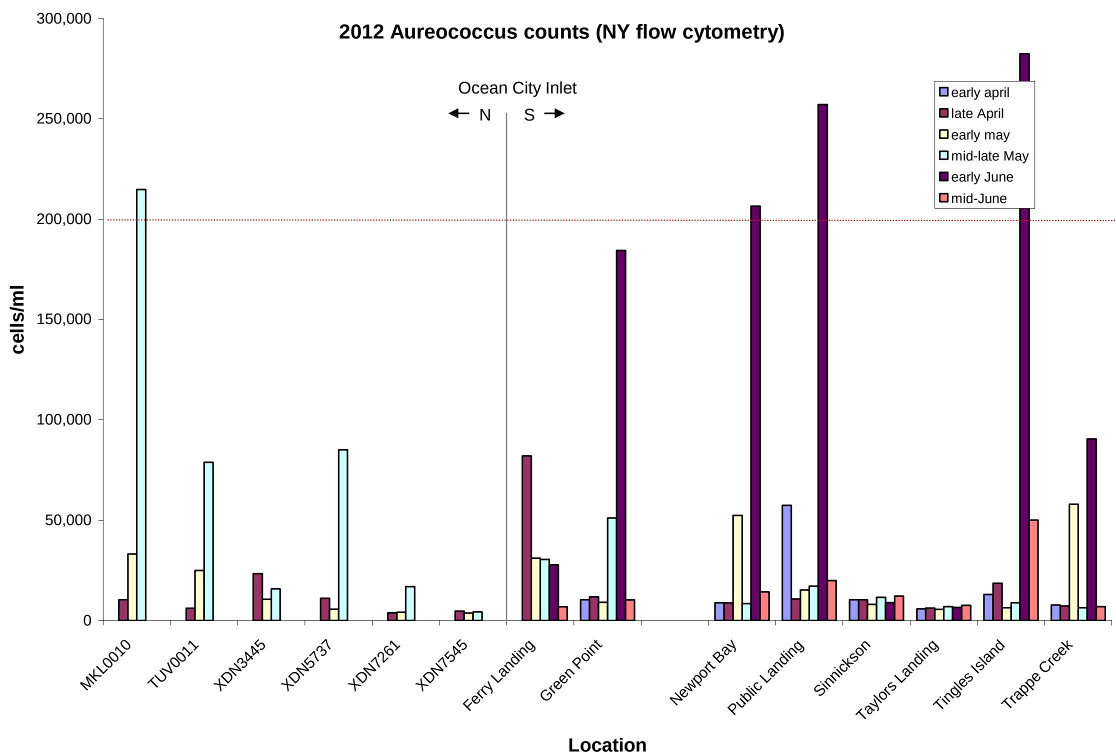

Figure 6.1.11 2012 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

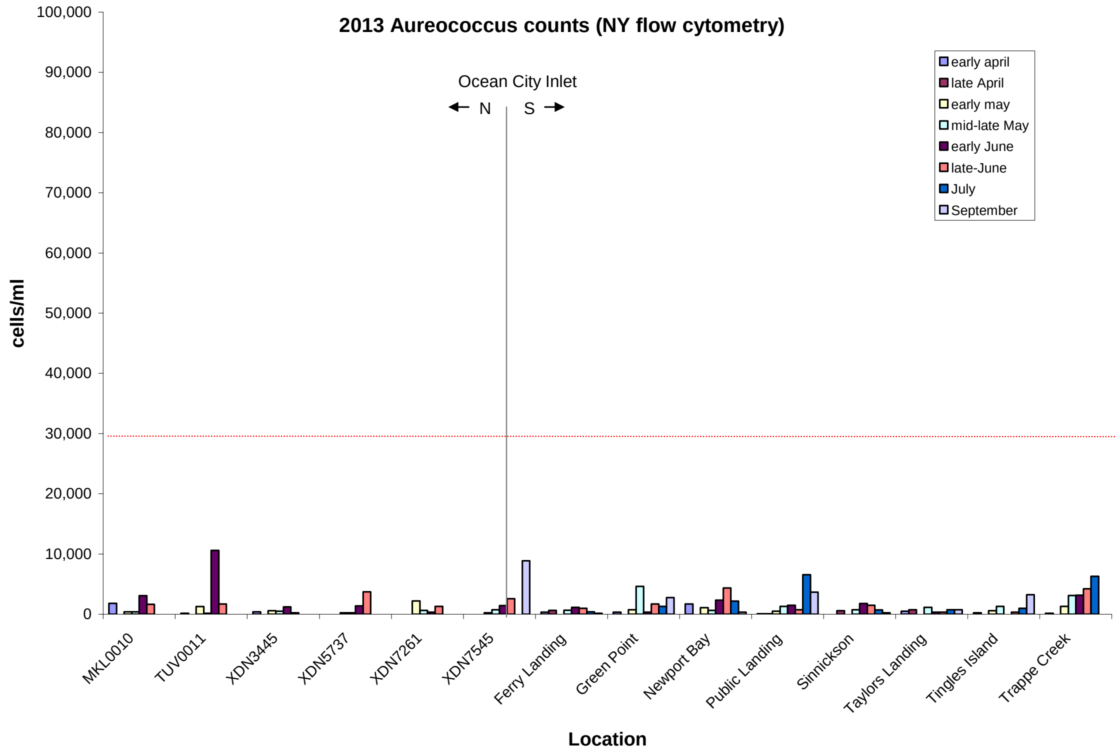

Figure 6.1.12 2013 Brown Tide, *Aureococcus anafagefferens*, cell counts at 14 stations.

Chapter 6.2

Assessment of harmful algae bloom species in the Maryland Coastal Bays

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Abstract
Thirteen potentially harmful algae taxa have been identified in the Maryland Coastal Bays: *Aureococcus anophagefferens* (brown tide), *Pfiesteria piscicida* and *P. shumwayae*, *Chloromorum/ Chattonella* spp., *Heterosigma akashiwo, Fibrocapsa japonica*, *Prorocentrum minimum*, *Dinophysis* spp., *Amphidinium* spp., *Pseudo-nitzchia* spp., *Karlodinium micrum* and two macroalgae genera (*Gracilaria, Chaetomorpha*). Presence of potentially toxic species is richest in the polluted tributaries of St. Martin River and Newport Bay. Approximately 5% of the phytoplankton species identified for Maryland's Coastal Bays represent potentially harmful algal bloom (HAB) species. The HABs are recognized for their potentially toxic properties and, in some cases, their ability to produce large blooms negatively affecting light and dissolved oxygen resources. Brown tide (*Aureococcus anophagefferens*) has been the most widespread and prolific HAB species in the area in recent years, producing growth impacts to juvenile clams in test studies and potential impacts to sea grass distribution and growth (see Chapter 7.1). Macroalgal fluctuations may be evidence of a system balancing on the edge of a eutrophic (nutrient-enriched) state (see chapter 4). No evidence of toxic activity has been detected among the Coastal Bays phytoplankton. However, species such as *Pseudo-nitzschia seriata*, *Prorocentrum minimum*, *Pfiesteria piscicida, Dinophysis acuminata* and *Karlodinium micrum* have produced positive toxic bioassays or generated detectable toxins in Chesapeake Bay. *Pfiesteria piscicida* was retrospectively considered as the likely causative organism in a large historical fish kill on the Indian River, Delaware. Similarly *Chloromorum toxicum* (aka *Chattonella* cf. *verruculosa*) was implicated in a large fish kill and persistent brevetoxins detected in Delaware's Rehoboth Bay during 2000. Tracking potential HAB species diversity, abundance, distribution and toxic activity through time provides important indicators of environmental change for the Coastal Bays.

Introduction
Algae are important components of aquatic ecosystems, forming the base of the food chain by converting sunlight to energy (photosynthesis). Certain types of algae may become harmful if they occur in an unnaturally large abundance (termed a harmful algal bloom or HAB) or if they produce a toxin that can harm aquatic life or humans. HABs are increasing worldwide. Many have been related to increases of nutrients from human activities. Blooms of harmful algae cause the potential for economic loss related to decreased recreational and commercial fishing, and tourism.

Monitoring
Biomonitoring programs identify species and estimate abundance of algae through microscope counts and genetic probe technologies. There are recognized thresholds for some HABs from

regions in the world where particular organisms have presented chronic problems to human health and the environment. Such threshold levels have been used by managers or industries to initiate shellfish closures, beach closures and intensify monitoring which can include toxin testing. Toxin testing may proceed if human or living resource impacts are observed (Table 6.2.1). While no algae has shown toxicity from Maryland's Coastal Bays, some of the same organisms have proven toxic along eastern seaboard and in particular in the Chesapeake and Delaware bays. The list of HABs and published thresholds of management interest are being used here as a means of producing an environmental indicator for tracking by site, watershed and the bays overall: Threshold Level Exceedances of Abundance measured in samples for the list of recognized HABs in the region based on routine phytoplankton monitoring program results. For some species, no density threshold exists. The indicator may require evolving into toxin detections and exceedances of regulatory limits for toxin exposure as monitoring programs evolve with new technologies being brought online. A second indicator of relative condition may be the frequency of encounters for HAB species during routine monitoring. This information has been provided in the report.

***Draft* HAB Indicator:** threshold exceedances

Table 6.2.1 Summary of harmful algae species present in the coastal bays and associated threshold levels.

Species	Abundance Threshold	Comments
Akashiwo seanguienum	None	
Alexandrium sp.	500 cells/ml	
Amphidinium sp.	None available. Test for ciguatera toxin*.	**Amphidinium* has been found toxic in subtropical and tropical waters, not yet at temperate latitudes.
Aureococcus anophagefferens	Category 1 < 35,000 cells*ml^{-1} Category 2 $\geq$ 35,000 and $\leq$ 200,000 Category 3 > 200,000	Gastrich and Wazniak 2000
Chloromorum toxicum (Chattonella cf. verrculosa)	10,000 cells*ml^{-1} (Test for brevetoxin)	Estimated based on the 2000 Rehobeth Bay fish kill that included brevetoxin detection. Bourdelais et al. 2002.
Cyanobacteria	*Microcystis* 10,000 cells*ml^{-1} *Anabaena* *none* *Amphizomenon* *none* *Lyngbya* 10,000 cells*ml^{-1} *Oscillatoria* *none* *Synechococcus* 400,000 cells*ml^{-1}	
Dinophysis sp.	5 cells*ml^{-1} Test for okadaic acid.	Levels that can initiate further testing for toxins around the world.
Fibrocapsa japonica	None available, (Test for fibrocapsin or bioassay).	
Gonyaulax sp.	none	
Heterocapsa sp.	>100,000 cells*ml^{-1}	
Heterosigma akashiwo	1,000 cells*ml^{-1}	Average of 500-1,000 cells*ml^{-1} from fish kill events that require

		mitigation. Anderson et al.
Karlodinium micrum	10,000 cells*ml^{-1} Test for karlotoxin activity: hemolytic, cytotoxic and ichthyotoxic testing may occur.	Kempton et al. 2002 lower threshold for fish kill effects.
Pfiesteria piscicida, P. shumwayae	Low, Toxic bioassay tests required.	300 cells*ml^{-1} of *Pfiesteria* Complex Organisms has been considered but toxicity bioassays required.
Prorocentrum minimum	3,000 cells*ml^{-1} Bioassay toxicity tests – toxin is not yet characterized.	Initial effects thresholds on living resources, EPA 2003
Pseudo-nitzschia sp.	200-1000 cells*ml^{-1} Test for domoic acid (Some international standards available)	In Canada, Domoic acid only detected with > 1,000 cells*ml-1; New Zealand increases shellfish testing > 200 cells*ml^{-1} and closes shellfisheries > 500 cells*ml-1
Macroalgae	No threshold	

Status of potentially harmful algal bloom species

I. *Aureococcus anaphagefferens* (Brown Tide)

Brown Tides are not thought to be toxic in Maryland but are poor food for shellfish and produce such dense blooms that block light for underwater grasses. Below are results from the routine phytoplankton monitoring program for Brown tide using light microscopy; however, this small species generally requires a more specific technique to properly identify it. Since brown tide (*A. anophagefferens*) has been the most widespread and prolific HAB species in the area in recent years, producing growth impacts to juvenile clams in test studies and potential impacts to sea grass distribution and growth**,** DNR oversees a separate monitoring program for Brown Tide in cooperation with the National Park Service at Assateague Island (ASIS) and the Maryland Coastal Bays Program (MCBP) (see Chapter 6.1).

Routine light microscopy counts of *Aureococcus* in the Coastal Bays show peak blooms during the summers of 2006 and 2007. Blooms were also observed in fall of 2008 and summers of 2009, 2010 and lesser in 2011. Blooms have been found primarily in Chincoteague Bay and the Newport watershed and to a less degree in Turville and Manklin Creeks, the St Martin River and Isle of Wight Bay.

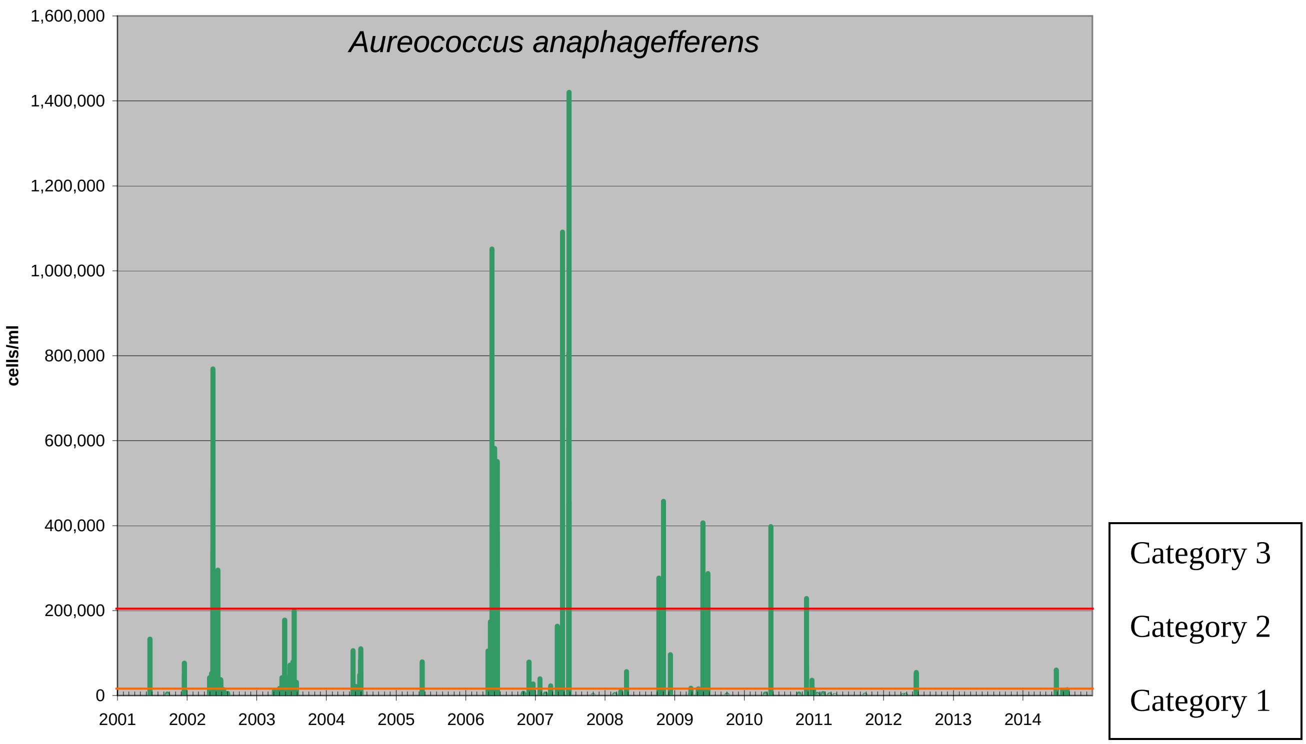

Figure 6.2.1 Occurrence of Brown Tide (*Aureococcus anaphagefferens* in the Maryland Coastal Bays between 2001-2014.

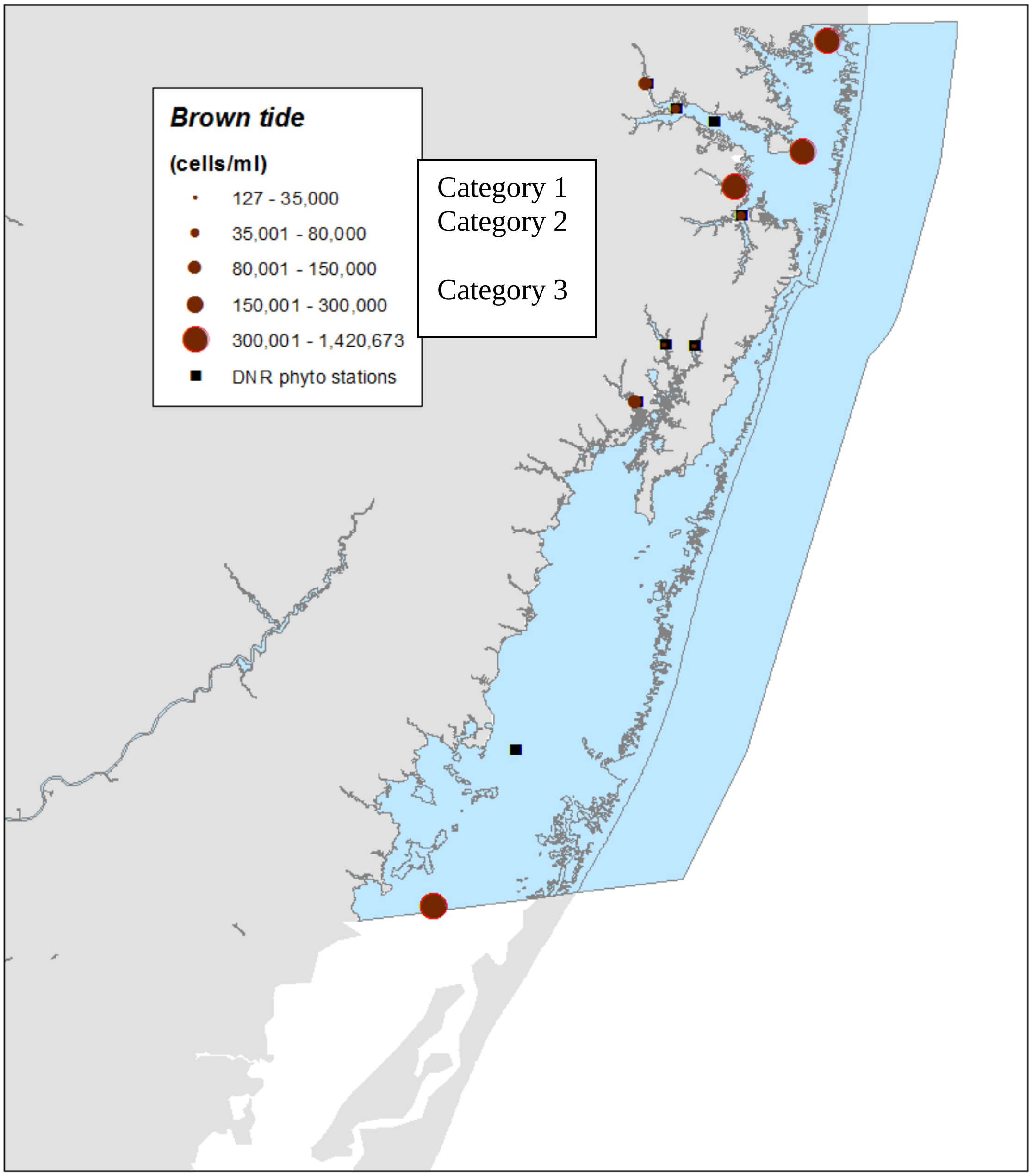

Figure 6.2.2 Distribution of Brown Tide (*Aureococcus anaphagefferens*) in the Maryland Coastal Bays between 2007-2014.

<u>II. Raphidophytes: Chloromorum Chattonella, Heterosigma, and Fibrocapsa</u>

The raphidophytes contain 12 known species, four such species have been identified from the Coastal Bays: *Chloromorum toxicum* (formerly *Chattonella* cf. *verruculosa*), *C. subsalsa, Heterosigma akashiwo* and *Fibrocapsa japonica*. Strains of *Chloromorum toxicum, H. akashiwo* and *F. japonica* have demonstrated toxic activity elsewhere in the world, however, there has been no evidence of toxins from any Raphidophytes in Maryland waters.

<u>*a. Chattonella*</u>

There are two species of *Chattonella* known in the Coastal Bays, *Chattonella* cf. *verruculosa aka Chloromorum toxicum* (may produce toxin), and *C. subsalsa* (not known to produce toxin). It includes the species *Chattonella subsalsa*, a bloom forming alga responsible for large scale fish deaths due to the synthesis of toxic compounds related to brevetoxin. *Chloromorum toxicum* is a potentially toxic species that has been associated with fish kills as near as in the Delaware Bays and can be potentially harmful to humans when producing brevetoxins. Brevetoxin is the same class of toxins as those produced by *Karenia brevis* (previously *Gymnodinium breve)*, associated with red tides, fish kills and sea mammal deaths in the Gulf of Mexico, and fish kills in Japan and Norway. Human exposure to brevetoxins can cause itchy skin, runny nose, watery eyes, wheezing and in some cases serious asthma attacks. Continued monitoring has not found the toxin in Maryland. Densities above 10,000 cells*ml^{-1} have been associated with toxin production and impacts on fish health (Bordelais et al. 2002). *Chloromorum toxicum* has been mainly found in Marshall Creek, Ayer Creek and St. Martin River.

Analysis of historic state phytoplankton data from intensive surveys of the St. Martin River in 1983 and 1992 suggested that *Chloromorum toxicum*, *Chatonella subsalsa* and *Fibrocapsa japonica* were present in what appears to be lower concentrations ten to twenty years ago than what has been observed in recent survey years. Historical identifications of Raphidophytes are based on journal drawings of cells identified in the Maryland Department of Environment monitoring program (MDE) (Walt Butler, Maryland Department of Natural Resources, Personal communication).

2007 Ten occurrences of *Chatonella* (8 *Chattonella subsalsa* and two *Chatonella cf)* were documented but all remained below 3,000 cells*ml^{-1}. Presence was limited to Ayres and Trappe Creeks.

2008 A *Chattonella subsalsa* bloom was documented in Ayres Creek on August 21 (12,954 cells*ml^{-1}). It was also present in Turville and Trappe Creeks (<300 cells*ml^{-1}) in July and August respectively. *Chloromorum toxicum* was detected cells*ml$^{\mathbf{-1}}$.

2009 A bloom was detected in July in Ayres Creek (56,515 cells*ml^{-1}) and just below bloom threshold levels were also detected in Trappe Creek (9,906 cells*ml^{-1}). No toxicity testing was performed. By August both blooms had dissipated to less that 2,600 cells*ml^{-1}.

2010 *Chattonella subsalsa* was detected three times in both Ayres and Trappe Creeks in July and August below bloom levels (254-6,350 cells*ml^{-1}). *Chloromorum toxicum* was detected in Turville, Bishopville and Marshal Creek.

2011 *Chattonella subsalsa* was again detected three times in both Ayres and Trappe Creeks in July and August below bloom levels (1-3,810 cells*ml^{-1}). *Chloromorum toxicum* was detected Ayres and Trappe Creeks in July and in Bishopville during the fall.

2012 *Chattonella subsalsa* was detected in July in Ayres and Trappe Creeks at low concentrations (633 and 1,899 cells*ml^{-1}respectively).

2013 *Chloromorum toxicum* (*Chattonella sp.)* was detected two times in 2013 at background levels (317 cells*ml^{-1}) in Ayres and Marshall Creeks.

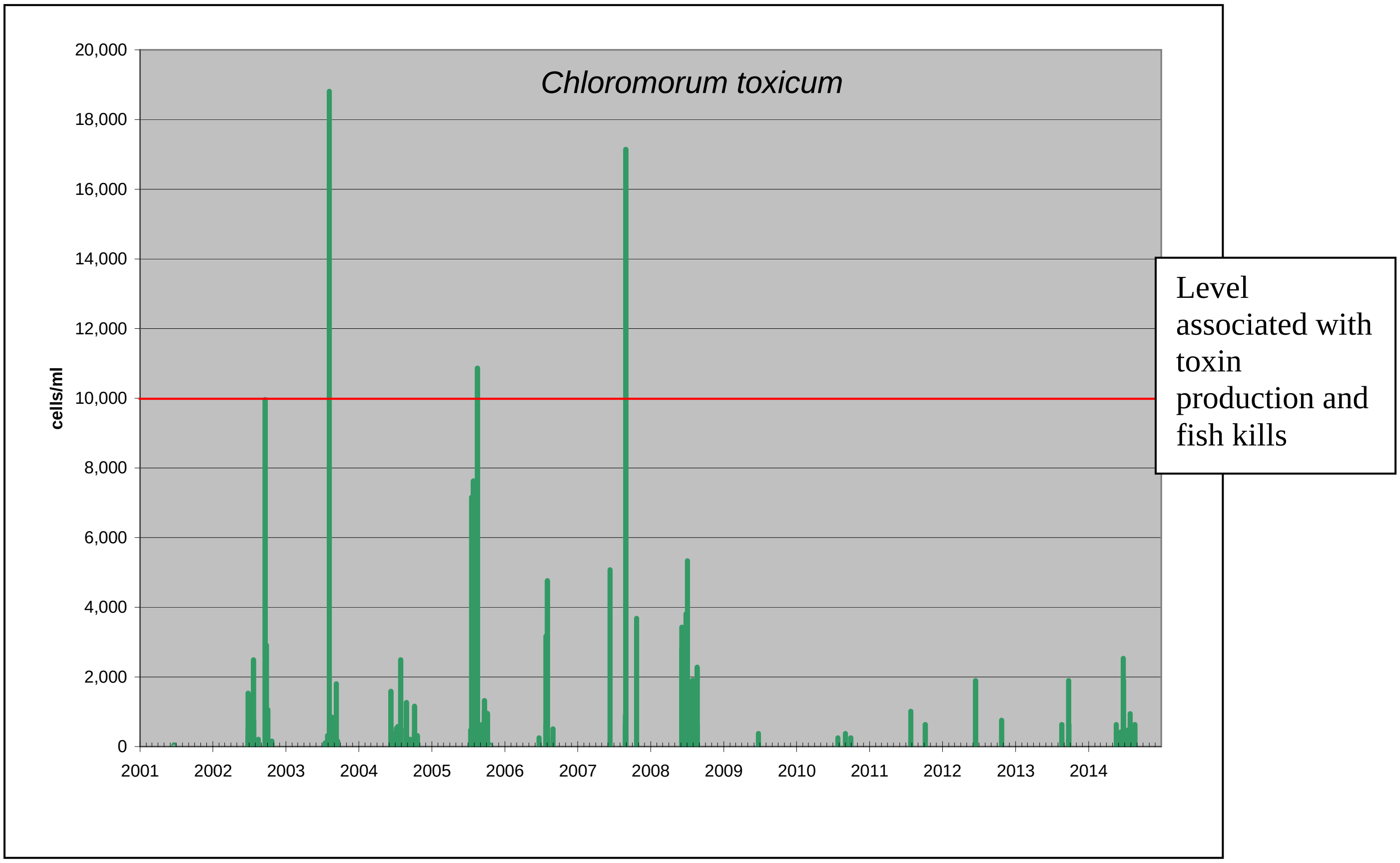

Figure 6.2.3 Occurrence of *Chloromorum toxicum* in the Maryland Coastal Bays between 2001-2014.

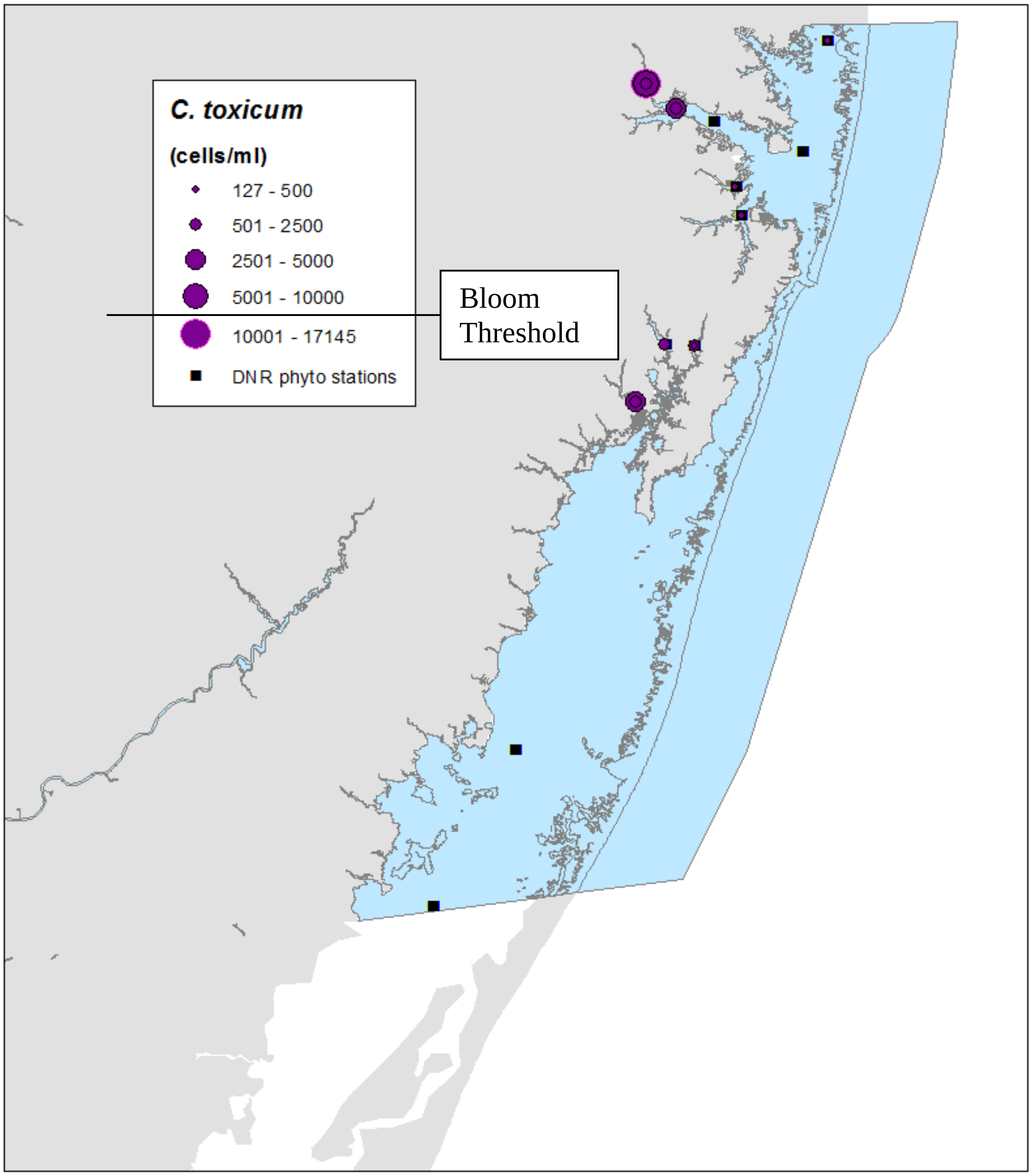

Figure 6.2.4 Distribution of *Chloromorum toxicum* in the Maryland Coastal Bays between 2007-2014.

b. *Heterosigma*

Heterosigma akashiwo has been found on both coasts of the United States (Hargraves and Maranda 2002) and is considered the causative organism involved in offshore fish farm kills in Washington State. Net-penned fish deaths related to *Heterosigma* have been particularly prominent in the northeast Pacific Ocean, notably around Japan. Predictability of blooms has been most related to temperature (warmer season waters >15 degrees C) and moderate salinity (approximately 15 ppt) in the coastal zone (Li and Smayda 2000, Connell and Jacobs 1997). Blooms have been observed to persist as long as stable water stratification persists in the warmer months. An unidentified ichthyotoxin (i.e., fish killing toxin) has been suggested as the causative agent in the mariculture fish kills. No documented effects to humans are evident from such blooms.

2007 *H. akashiwo* was detected in Trappe Creek (TRC0043) and Manklin Creek (MKL0010) in September and October respectively at background levels (1-127 cells*ml^{-1}).

2008 A bloom of *H. akashiwo* was detected in Marshall (MSL0011) in May (41,910 cells*ml^{-1}). Another bloom was detected in Ayres Creek (AYR0017) in June (1270 cells*ml^{-1}). Neither showed evidence of toxic activity.

2009 A bloom of *H. akashiwo* was found in June in Ayres Creek (AYR0017) and Trappe Creek (TRC0043) with concentrations of 25,718 and 1,143 cells*ml^{-1}respectively. *H. akashiwo* was also noted in Marshall Creek at 508 cells*ml^{-1}.

2010 *H. akashiwo* was observed in Trappe Creek (508 cells/ml) and Ayres Creek (635 cells*ml^{-1}) in June and September respectively.

2011 A bloom of *H. akashiwo* was documented in Turville Creek in September of 2011 (8,890 cells*ml^{-1}).

2012 *Heterosigma* was not detected in 2012.

2013 Both Ayres and Marshall Creeks had occurrences of *H. akashiwo* in May (1,400 and 1,600 cells*ml^{-1} respectively). It was also noted in Trappe, Manklin and Turville creeks at levels well below bloom thresholds.

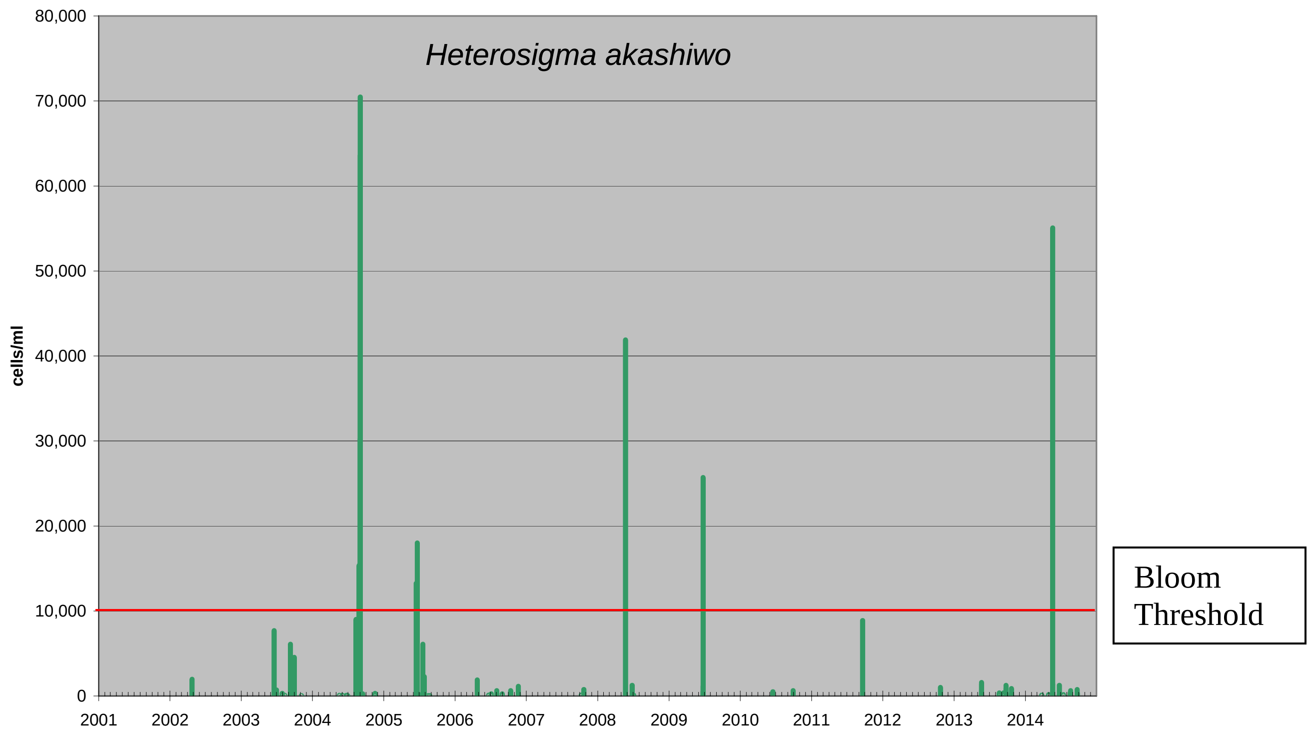

Figure 6.2.5 Occurrence of *Heterosigma akashiwo* in the Maryland Coastal Bays between 2001-2014.

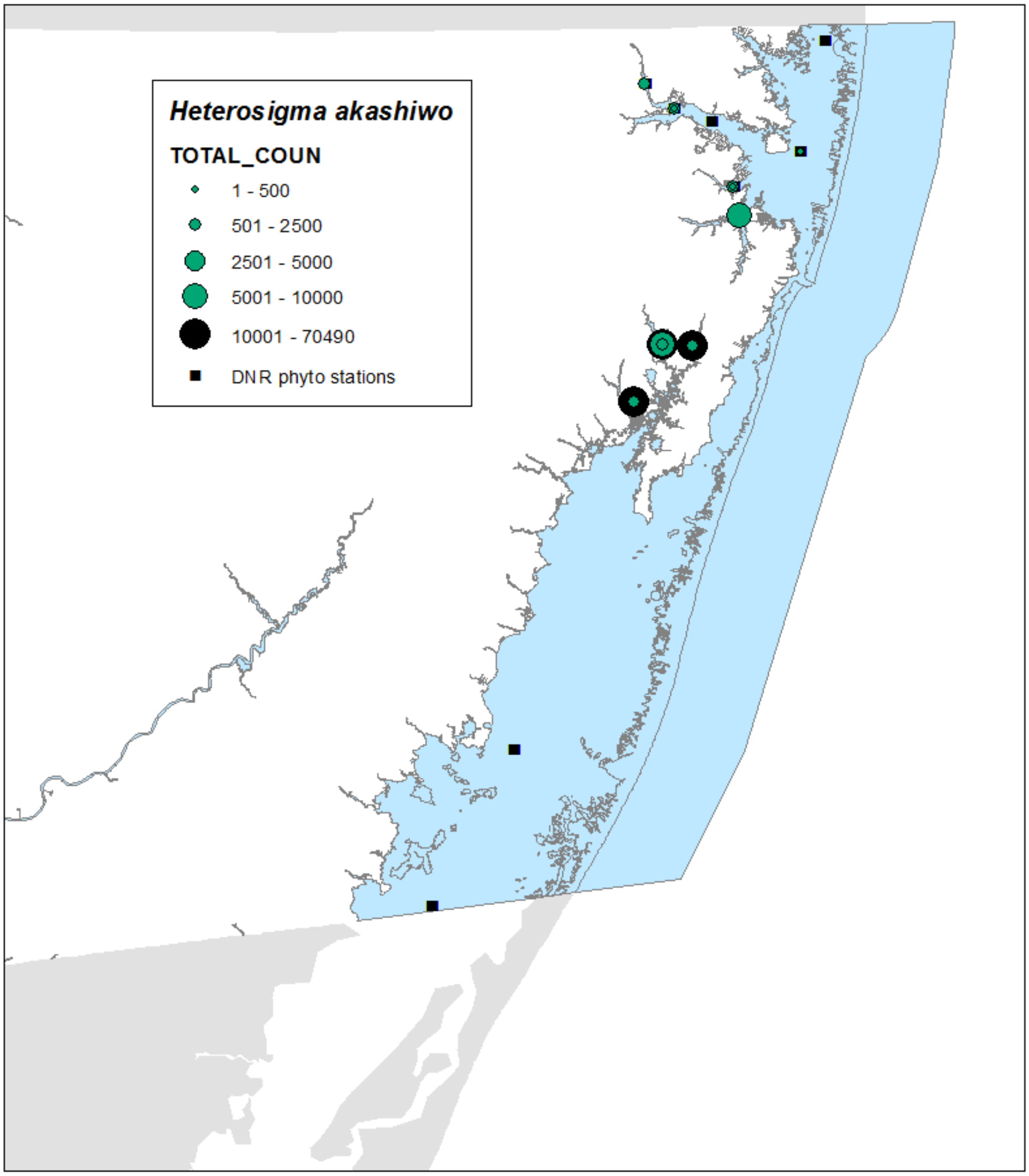

Figure 6.2.6 Distribution of *Heterosigma akashiwo* in the Maryland Coastal Bays 2007-2013.

c. *Fibrocapsa*

Fibrocapsa has had devastating impacts on mariculture operations in Japan. Strains of *F. japonica* collected from the North Sea in Europe have been capable of producing toxin that killed fish in laboratory tank studies. The body tissue of two seals that died in the Wadden Sea of Germany were found to have high levels of the toxin Fibrocapsin. North Sea strains of *F. japonica* grow well under laboratory conditions of 11-25^{o}C, 20-30 ppt salinity, and N/P ratio of 24. No samples were sent for toxin analyses.

2007 Low concentration detected in Ayres Creek in August (254 cells*ml^{-1}). A September bloom >1,000 cells*ml^{-1} was detected in Bishopville Prong.

2008 One bloom level cell count (>1,000 cells*ml^{-1}) was detected in the upper St Martin River during August (1,143 cells*ml^{-1}).

2009 No blooms detected.

2010 Blooms were observed in Bishopville Prong in early August (2,540 cells*ml^{-1}) and below bloom level counts detected in Ayres Creek in September (635 cells*ml^{-1}).

2011 No blooms detected

2012 No blooms detected

2013 Highest bloom recorded was detected in Marshall Creek in January (5,000 cells*ml^{-1}).

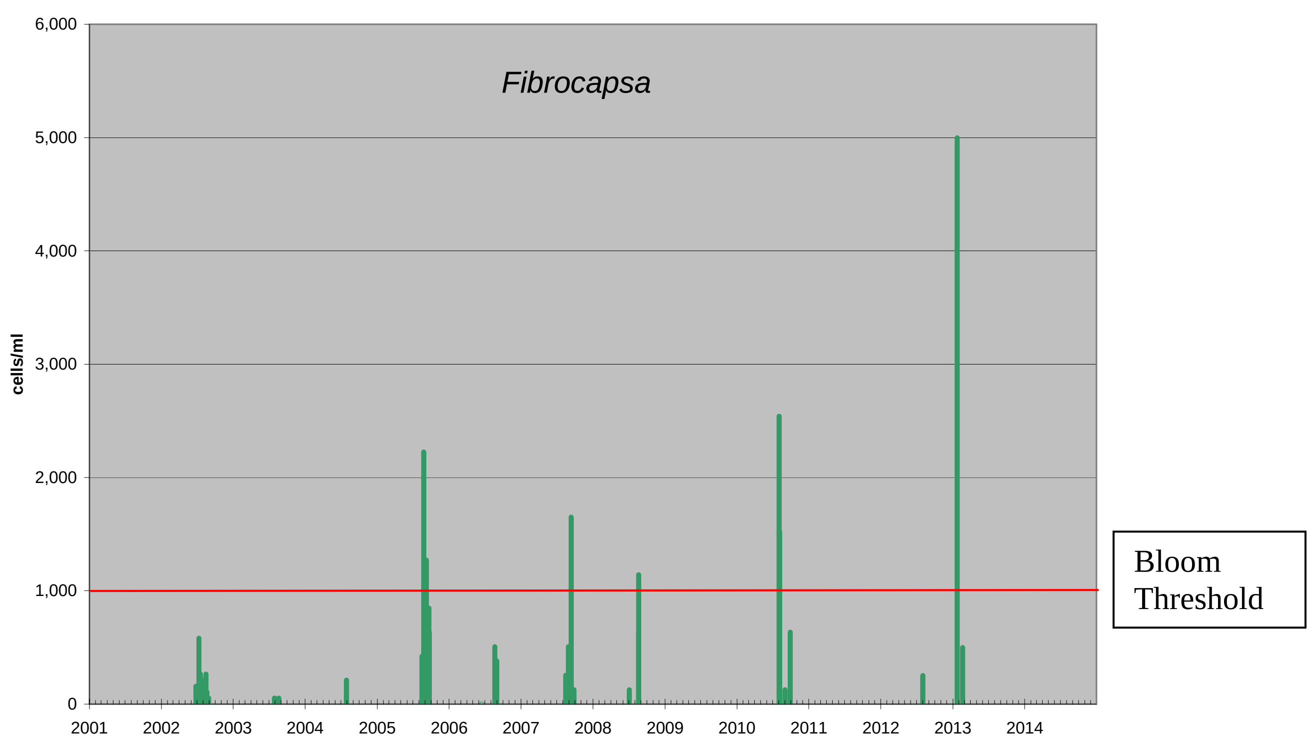

Figure 6.2.7 Occurrence of *Fibrocapsa* in the Maryland Coastal Bays between 2001-2014.

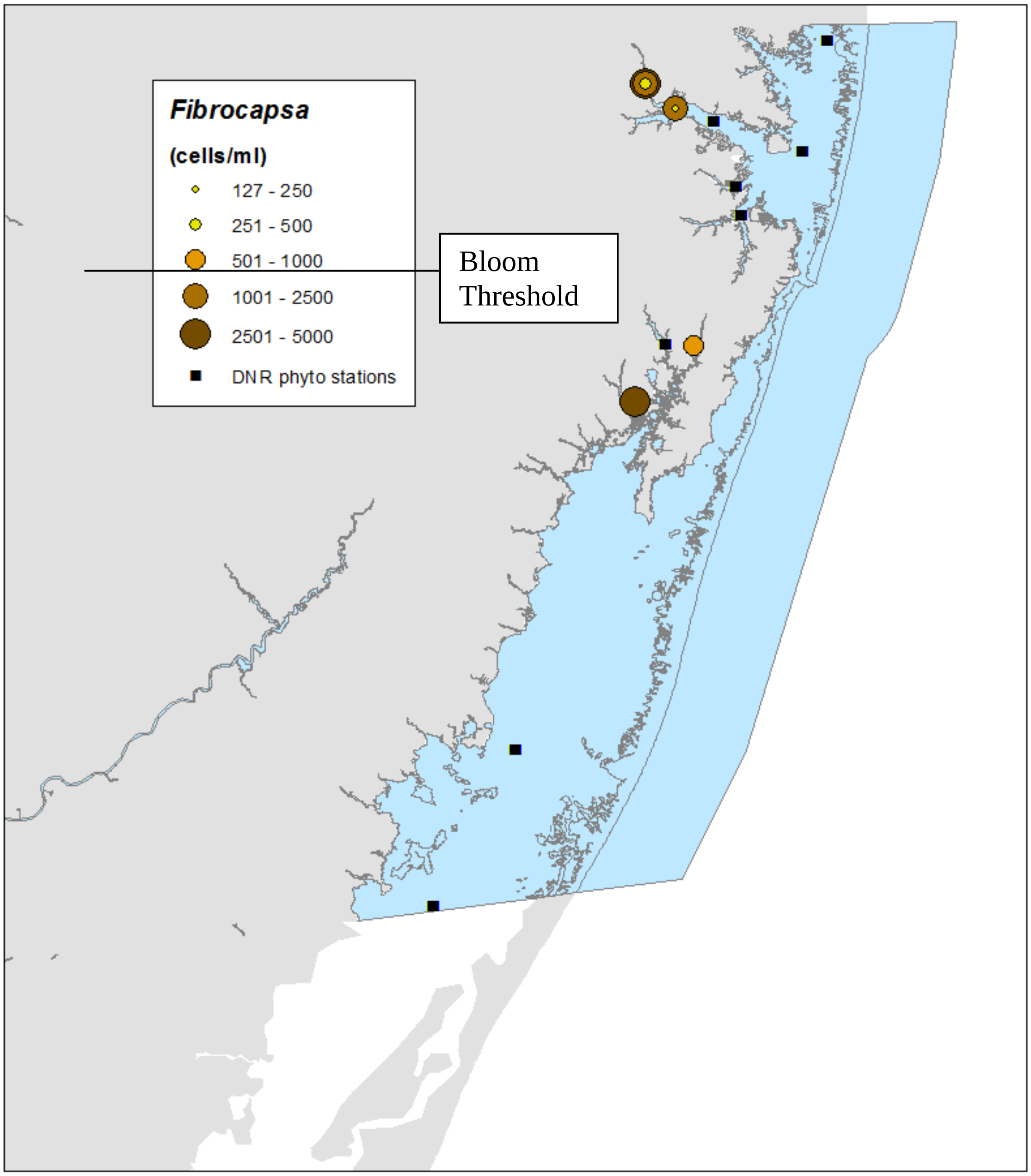

Figure 6.2.8 Distribution of *Fibrocapsa* in the Maryland Coastal Bays (2007-2014).

III. <u>*Pfiesteria: P. piscidia and P. shumwayae*</u>

There are two species of *Pfiesteria*, *Pfiesteria piscicida* and *Pfiesteria shumwayae*, both of which are potentially toxic to fish and people. *Pfiesteria* has been shown to have a highly complex life-cycle with more than 24 reported forms that live in either the bay sediment or water.

Pfiesteria was first detected with targeted sampling in the Coastal Bays of Maryland beginning in 1998. Water and sediment surveys have been conducted in the Coastal Bays using Polymerase Chain Reaction (PCR) techniques to detect these potentially harmful species. Rapid response efforts by MDE and DNR have examined fish kills annually since 2000 occasionally detecting *Pfiesteria* species at the events. Bioassays, however, have all been negative for signs of toxicity. No toxic Pfiesteria has ever been detected in Maryland's Coastal Bays. The presence of *Pfiesteria* has historically been in the Newport Bay system (Ayres, Trappe, Marshall and Newport Creeks).

2007-2012 No *Pfiesteria* cells were observed.

2013 Pi*esteria*-like species were detected during December in the upper St Martin River (low concentration of 506 cells*ml^{-1}). .

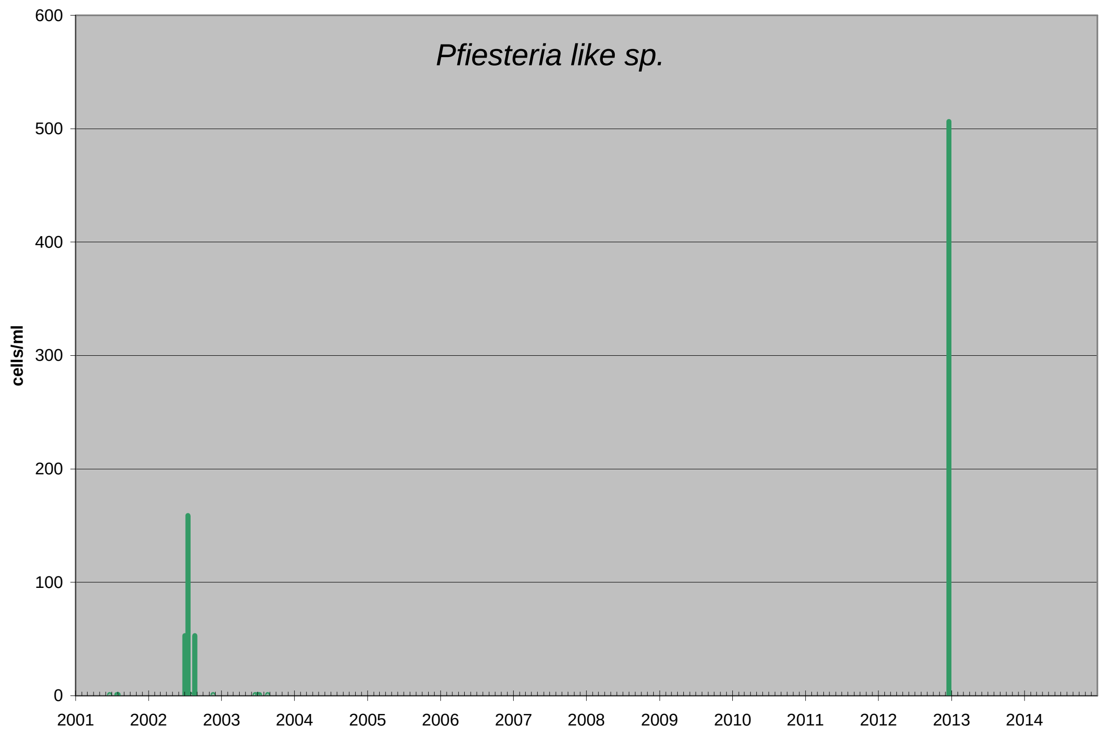

Figure 6.2.9 Occurrence of *Pfiesteria*-like species in the Maryland Coastal Bays between 2001-2014.

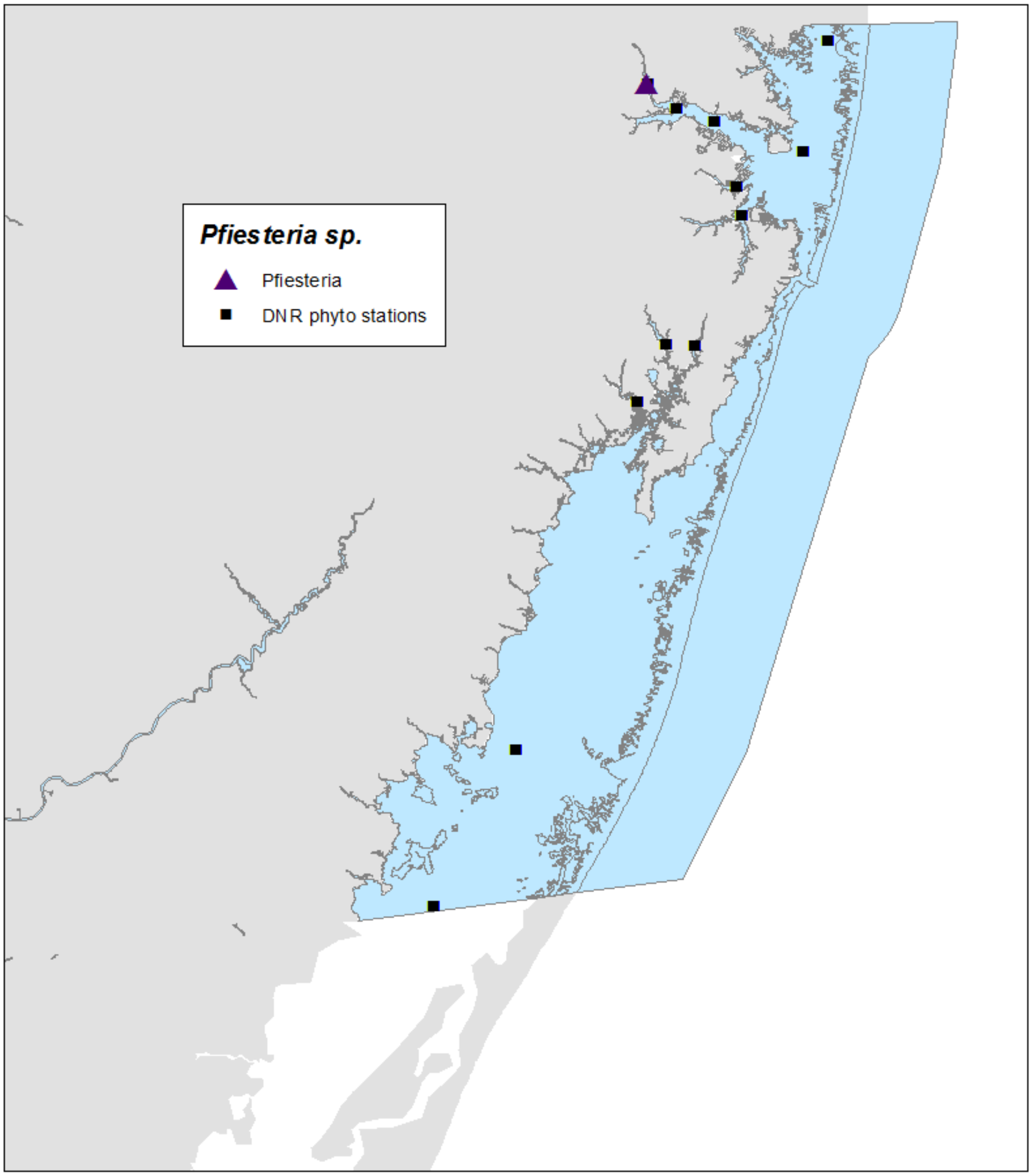

Figure 6.2.10 Distribution of *Pfiestera* in the Maryland Coastal Bays between 2007-2014.

IV. <u>*Prorocentrum*</u>

Prorocentrum blooms have been linked to widespread harmful ecosystem impacts including: anoxic and hypoxic events, finfish kills, aquaculture shellfish kills, submerged aquatic vegetation losses, and toxicity bioassays. Such events in this region are typically related to the planktonic species *Prorocentrum minimum*. In the Coastal Bays, blooms have occurred in April and May in mid-salinity waters (upper parts of creeks and rivers). This species is considered potentially toxic to humans with rare cases of associated shellfish poisoning worldwide. No such cases related to *P. minimum* have been reported from Maryland waters although isolates from the Choptank River (Chesapeake Bay watershed) indicated toxicity to shellfish larvae in laboratory testing. High biomass blooms have also been responsible for low dissolved oxygen events leading to fish kills in Chesapeake Bay embayments and an extended bloom in 2000 is suspected in declines of SAV in the mid-Chesapeake Bay region for 2001.

Impacts on bay organisms have been identified at concentrations as low as 3,000 cells*ml^{-1} (EPA 2003) providing a threshold for the tracking and assessment of blooms. Threshold exceedances were recorded only once during 2001 and 2002 in the St. Martin River. Impacts of high density blooms of *Prorocentrum* are most likely when blooms exceed 10,000 cells*ml^{-1}.

2007 Significant blooms were observed January through March in the Upper St Martins, Bishopville Prong, Marshall and Turville Creeks. Blooms were observed again in May in Bishopville Prong.

2008 No significant blooms observed.

2009 Bloom were detected in April and May in the upper St Martin River (19,685 cells*ml^{-1}), Bishopville Prong (~65,000 cells*ml^{-1}) and Turville Creek (>17,000 cells*ml^{-1}).

2010 No significant blooms observed. Cells counts above 3,000 cells*ml^{-1} (threshold which will discolor water) were seen in Marshall, Trappe and Newport Creeks.

2011 No blooms detected.

2012 A bloom was observed in January in the St Martin River, Bishopville Prong, due to a warm spell (19,177 cells*ml^{-1}). The rest of the year no blooms were detected.

2013 Significant blooms (>10,000 cells*ml^{-1}) were observed in Marshall Creek, Newport Creek and Trappe Creek in March and April.

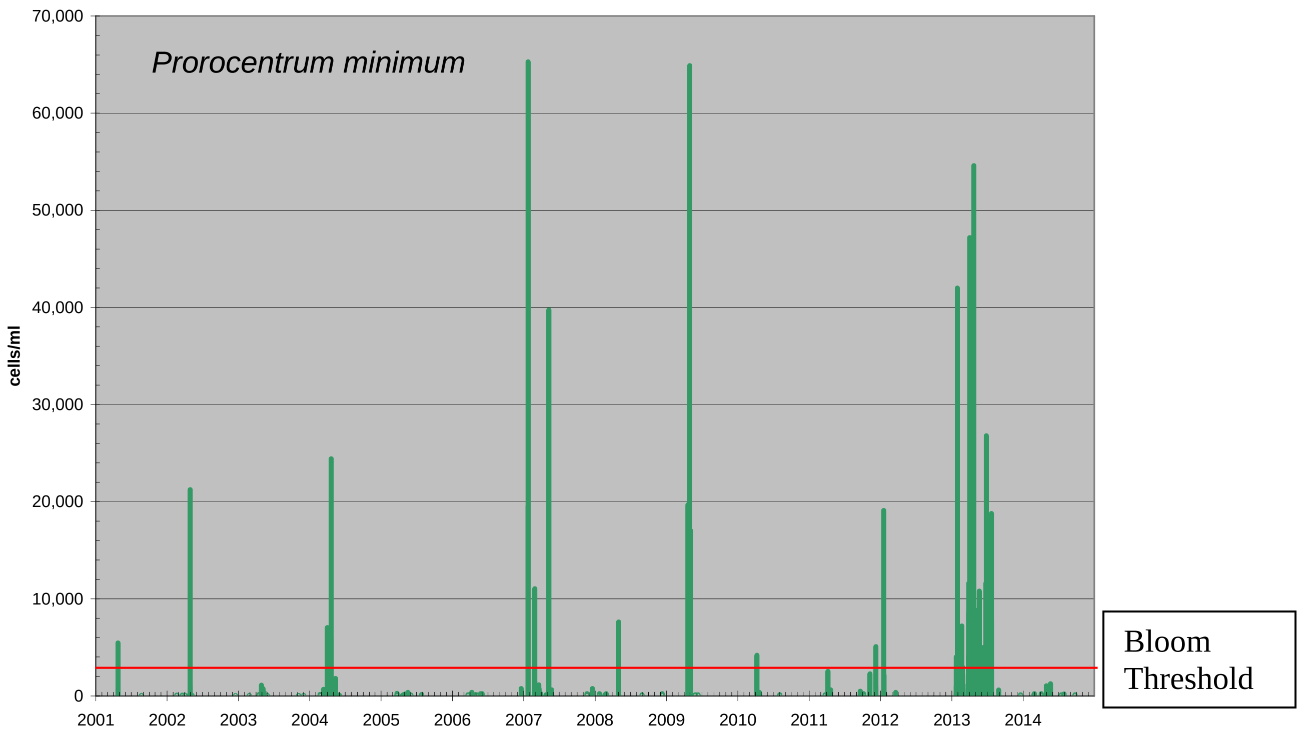

Figure 6.2.11 Occurrence of *Prorocentrum minimum* in the Maryland Coastal Bays 2001-2014.

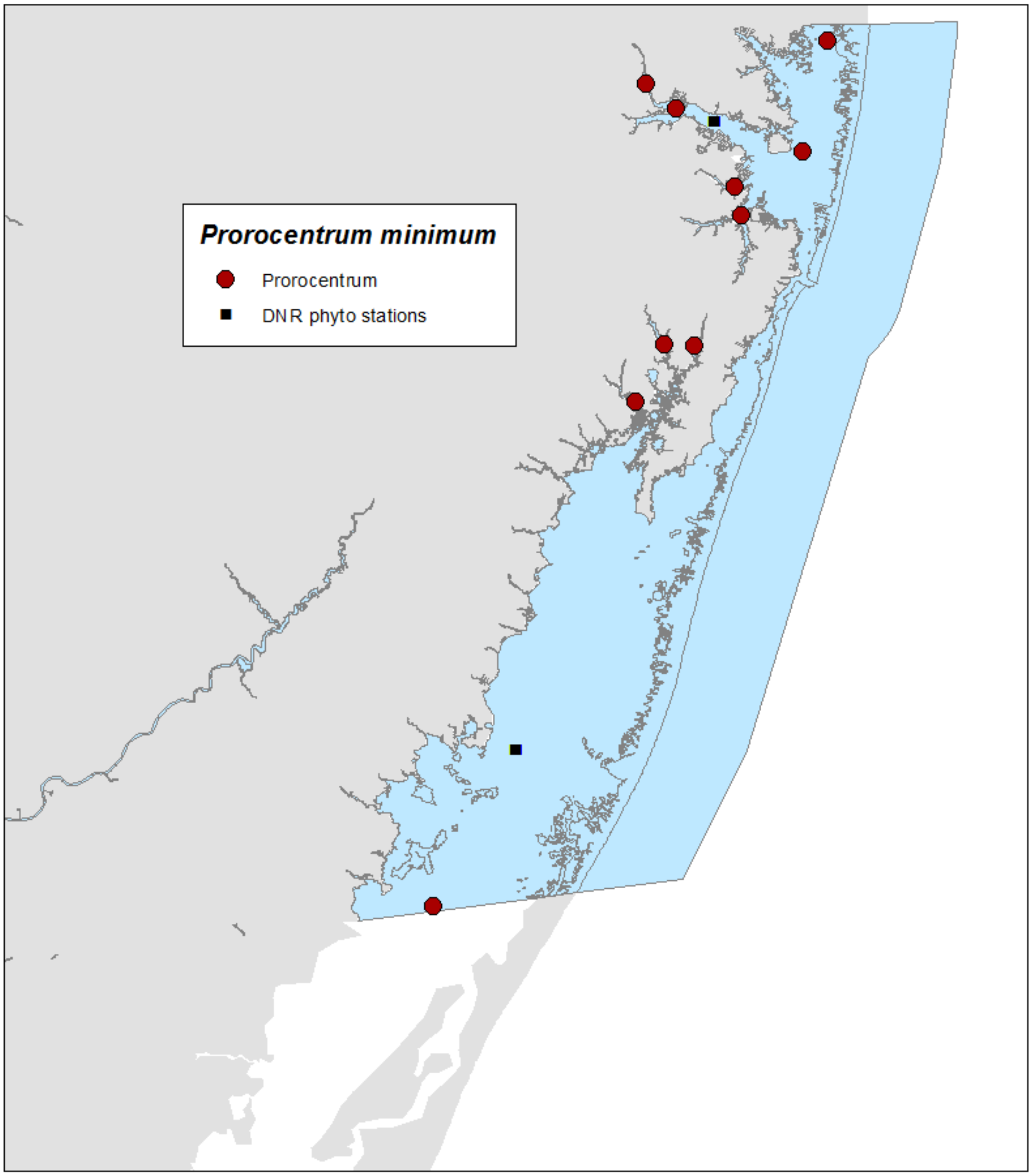

Figure 6.2.12 Distrbution of *Prorocoentrum minimum* in the Maryland Coastal Bays, 2007-2014.

V. *Dinophysis*

Dinophysis acuminata has been the most commonly encountered representative of this genus in Maryland's Coastal Bays. The genus *Dinophysis* is represented in Chesapeake Bay by five species (*D. acuminata, D. acuta, D. fortii, D. caudata* and *D. norvegica*) and are all known to produce okadaic acid or other toxins causing Diarrhetic Shellfish Poisoning (DSP) (Marshall 1996). DSP has occurred in humans consuming the contaminated shellfish resulting in symptoms that include intestinal discomfort, abdominal pain, nausea, headache, chills and vomiting. No cases of DSP have been reported in Maryland.

Management actions in the countries of Italy, Norway and Denmark to protect human health against DSP includes intensified monitoring of shellfish harvest waters, toxin testing of the shellfish and application of restrictions or closures of the fisheries. Thresholds of 500-1,200 cells*L^{-1} are used by managers in these countries to initiate temporary closures or intensified monitoring; toxin test results ultimately determine the extent of actions necessary (Anderson et al. 2001). Europe and Japan appear to be the most highly affected areas for cases of DSP, however, outbreaks in North America have been confirmed in Eastern Canada during 1990 and 1992. Okadaic acid was found in association with a *D. acuminata* bloom in 2002 on the Potomac River, however, levels were well below FDA levels for seafood safety. Despite thousands of documented cases of DSP worldwide since 1960, there are no reported fatalities associated with the illness.

A threshold 20x the minimum used in Europe (i.e., 0.5 x 20 = 10 cells*ml^{-1} threshold) has been implemented as a tracking indicator for this species. *Dinophysis* has been observed above threshold concentrations in Assawoman Bay, Isle of Wight and St. Martin River. Recently toxicity has been shown in the Coastal Bays and accumulation in shellfish. No shellfish in harvestable waters have shown levels above FDA thresholds and no closures have been implemented.

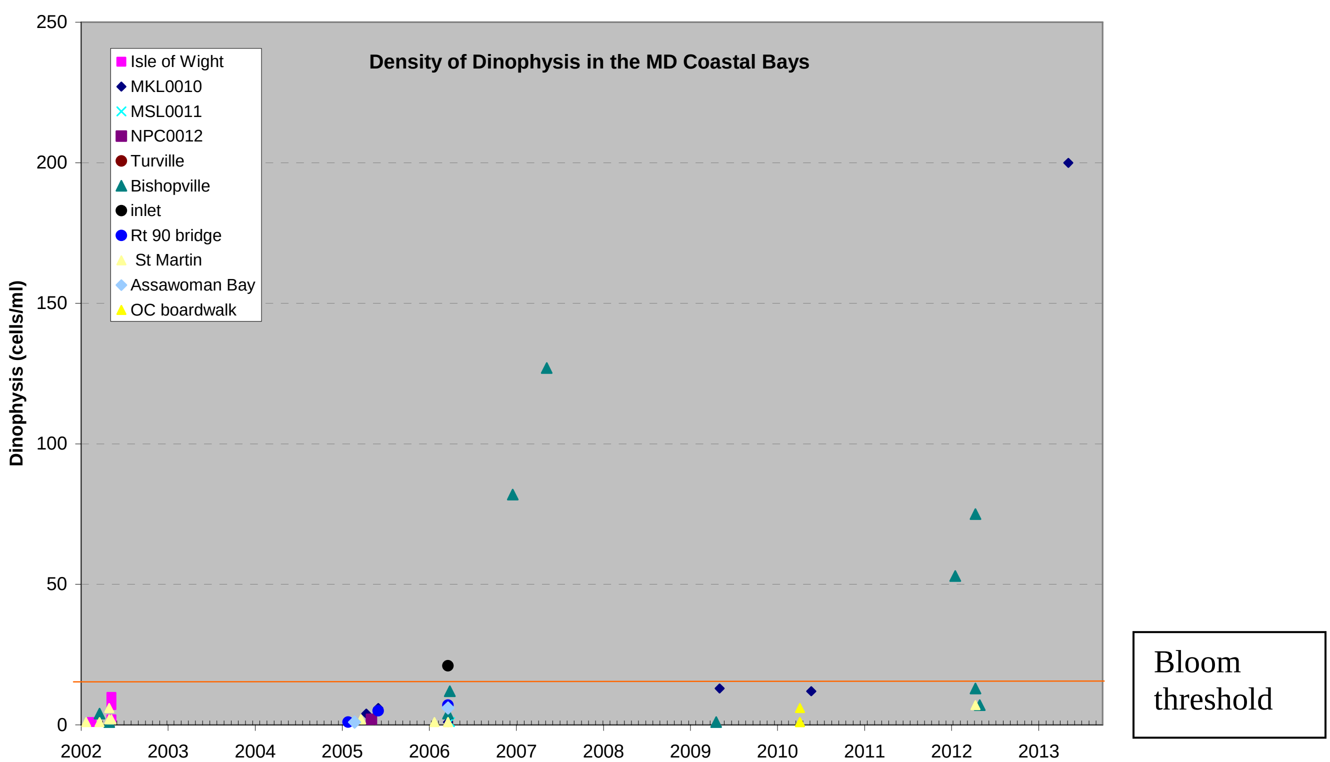

Figure 6.2.13 Occurrence of *Dinophysis sp.* at specific sites in the Maryland Coastal Bay from 2002-2014. Bloom threshold is 10 cells*ml^{-1}.

2007 Blooms of *Dinophysis* detected in May at Bishopville site (127 cells*ml^{-1}).

2008 No *Dinophysis* detected

2009 A bloom of *Dinophysis* was detected in Manklin and cells were present in Turville Creeks during May at 13 and 1 cells*ml^{-1} respectively.

2010 A bloom sample from Manklin creek in May (12 cells*ml^{-1}). A water sample was sent to FDA and confirmed DSP toxin presence in MD for the first time.

2011 No bloom level counts detected in routine samples; however, bloom levels were found in Turville Creek, Isle of Wight and Assawoman Bays during special study. Bloom in Bishopville, collected oyster for toxin analyses by FDA revealed toxin in shellfish. This is a no shellfish area.

2012 A bloom was observed in Bishopville Prong (53 and 75 cells*ml^{-1}). Mussels were collected for toxin analyses by U.S. Food and Drug Administration that revealed toxin above guidance levels. This is a no shellfish area. SPATT, solid phase adsorption toxin tracker, samplers indicated even higher toxin possible in Turville Creek (highest count 3 cells*ml^{-1}). Toxin also present in Manklin (count only 1 cells*ml^{-1}).

2013 Routine monitoring saw one bloom of *Dinophysis* in Manklin Creek during May (200 cells*ml^{-1}). An intensive cage study was also conducted in 2013 to compare the uptake of 'dinotoxins' in 4 bivalve species (scallops, mussels, oysters and clams) and the SPAT passive samplers. The study concluded that scallops take up the toxin most, followed by Clams and then oyster/mussels.

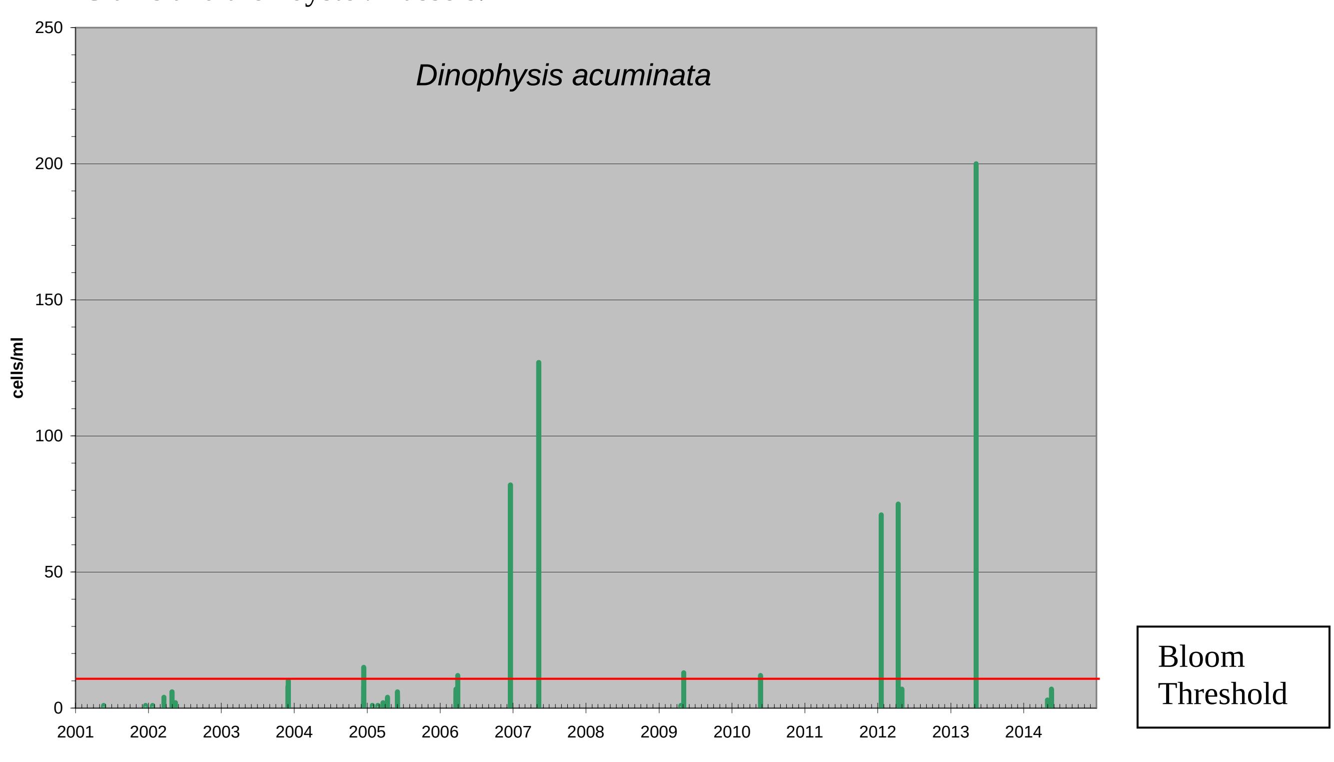

Figure 6.2.13b Occurrence of *Dinophysis sp.* in the Maryland Coastal Bays, 2001-2014.

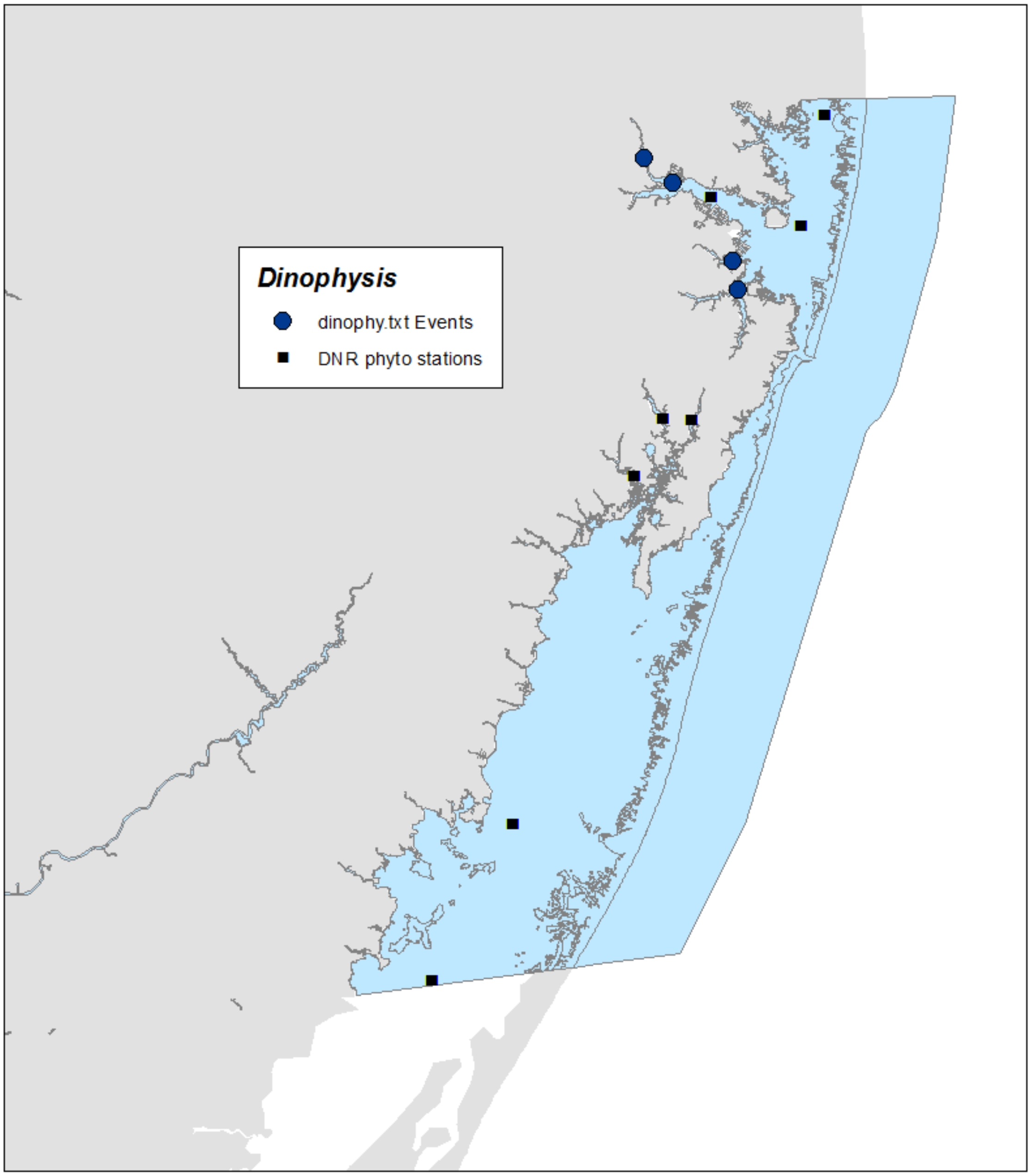

Figure 6.2.14 Distribution of *Dinophysis sp.* in the Maryland Coastal Bays (2007-2014).

VI. *Pseudo-nitzschia*

Diatoms in the genus *Pseudo-nitzschia* are recognized worldwide as potential producers of the toxin domoic acid (DA). Shellfish feeding on toxic *Pseudo-nitzschia* can accumulate domoic acid. Humans consuming the contaminated shellfish may subsequently experience Amnesic Shellfish Poisoning (ASP). Symptoms of ASP include vomiting, confusion, memory loss, coma or death. ASP was first identified on the east coast of North America at Prince Edward Island, Canada, in 1987. Despite a recall of all bivalve products from the Prince Edward Island region, the outbreak resulted in 107 illnesses that included 13 fatalities. In 1995, a shellfish closure occurred due to elevated levels of DA. Recent illnesses have only occurred from recreational harvests that have disregarded the shellfish closures.

In other countries: *Pseudo-nitzschia* cell densities of 200 cells*ml^{-1} of *P. seriata* are used in Denmark and 5-10 cells*ml^{-1} in New Zealand to trigger toxin testing of shellfish meats (Anderson et al. 2001). In New Zealand, the shellfish industry conducts voluntary closures of a fishery where cell densities measure > 5 x 10^5 cells*L^{-1} (Anderson et al. 2001). Canada has indicated detectable levels of DA in the shellfish at levels of at least 1,000 cells*ml^{-1} (Anderson et al. 2001).

In Maryland, low levels of domoic acid have been detected by Thessen and Stoeker 2008. However, blooms do not typically have high concentrations nor do they last

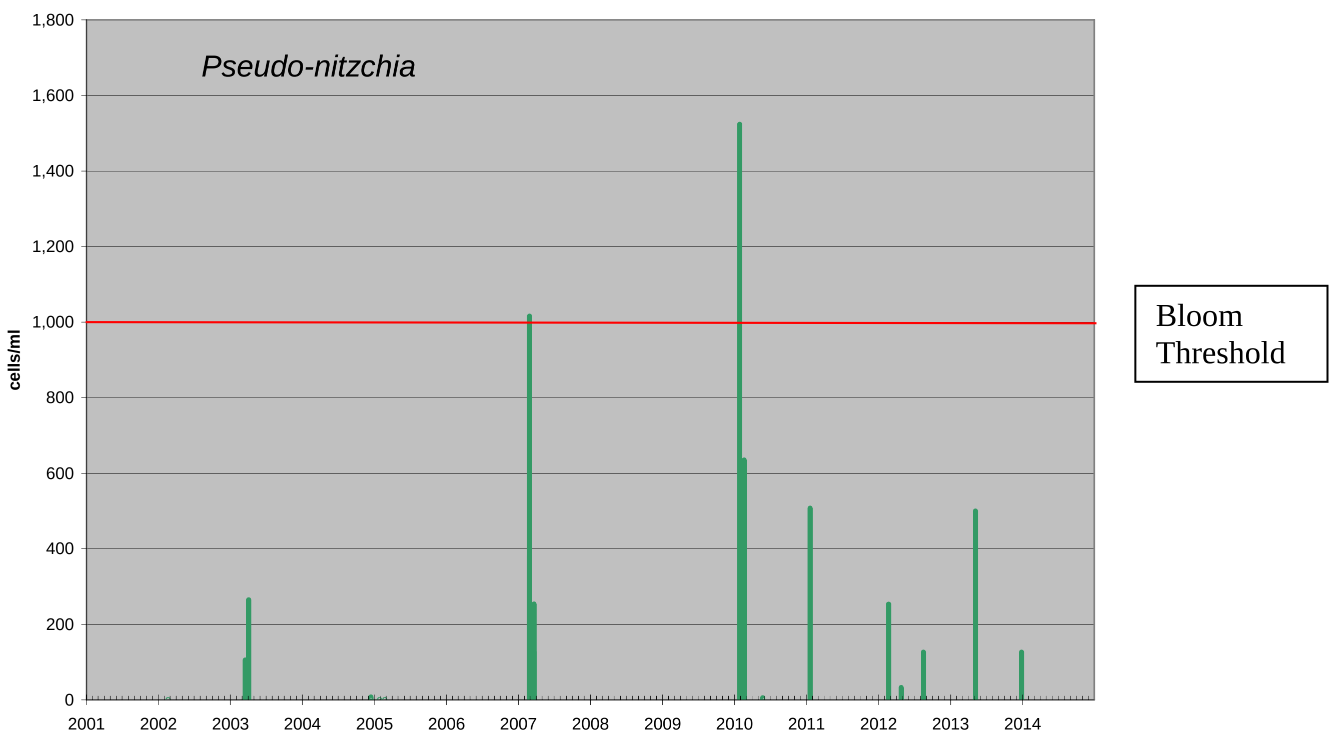

Figure 6.2.15 Occurrence of *Pseudo-nitzschia sp.* in the Maryland Coastal Bays (2001-2014). Bloom threshold is 1,000 cells*ml^{-1}.

2007 Bloom observed in Manklin Creek in February (1,016 cells*ml^{-1}) and also observed in Turville Creek and Isle of Wight Bay near the Rt. 90 bridge.

2008 No significant blooms observed.

2009 No significant blooms observed.

2010 Bloom observed (1,524 cells*ml^{-1}) during January in Isle of Wight Bay near the Rt. 90 bridge and lower counts observed in Turville and Manklin Creeks.

2011 No significant blooms observed.

2012 No significant blooms observed.

2013 No significant blooms observed. Present below bloom levels in Manklin Creek.

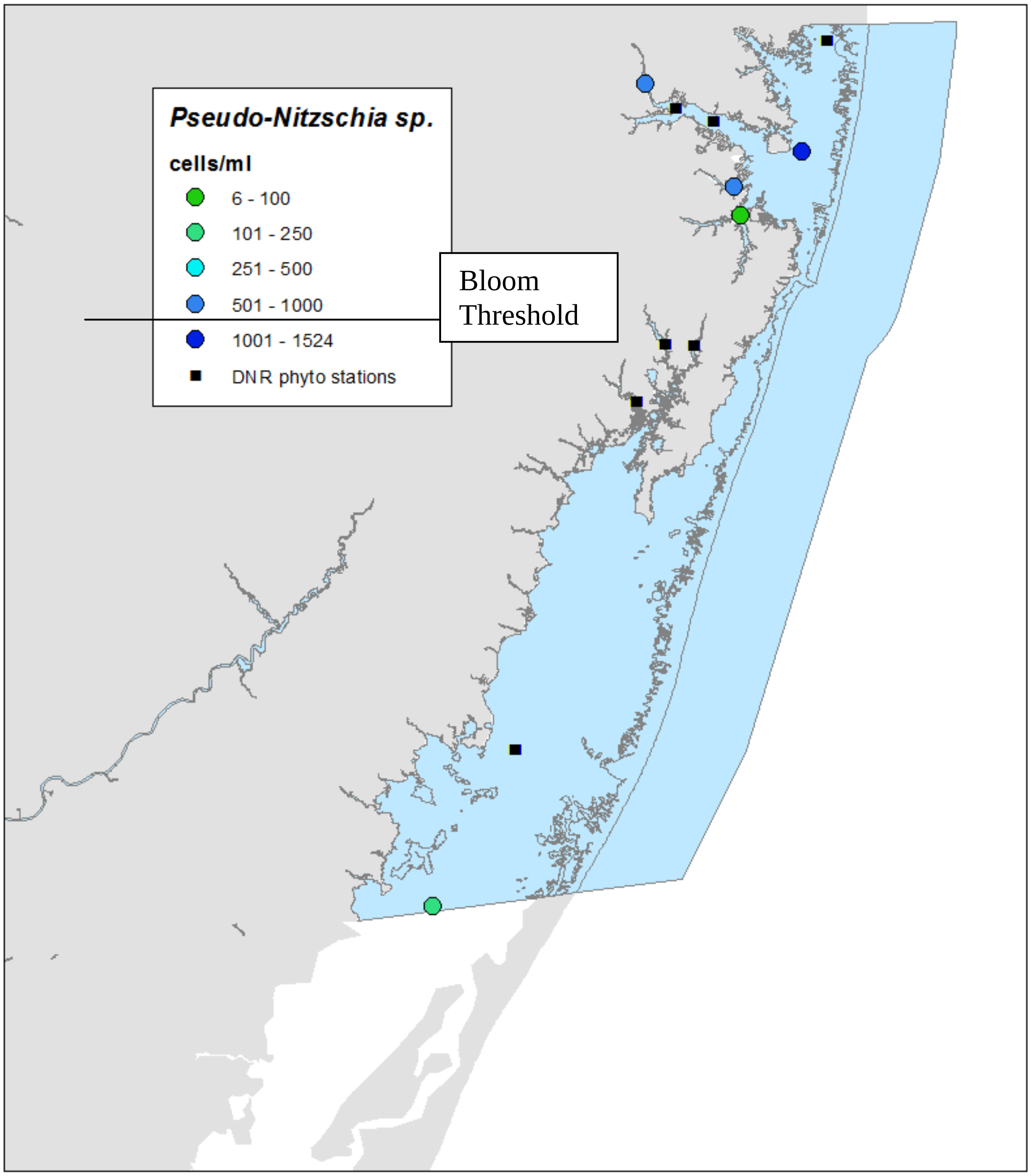

Figure 6.2.16 Distribution of *Pseudo-nitzschia sp.* in the Maryland Coastal Bays between 2007-2014.

VII. *Amphidinium*

The algae *Amphidinium operculatum* is an epi-benthic dinoflagellate was first found in Newport

Creek in October 1999 in very small numbers. This unusual organism was detected in a water sample through centrifuging 15 ml of the sample to look at another species. *Amphidinium* has been linked with ciguatera toxins in subtropical and tropical habitats. They are also known to produce several polyketides known as amphidinins. There is no evidence of toxicity for this species in the Coastal Bays.

Four occurrences of *Amphidinium spp*. were detected between 2007 and 2013 in water samples from the Coastal Bays. In March of 2007 in Turville Creek (TUV0011) and in November of 2009 in Ayres Creek (AYR0017) and last the species *A. glaucum* was observed in December of 2012 in Trappe Creek (TRC0043). Counts ranged from 1 cell/ml in Ayres Creek to 253 cells*ml^{-1} in Trappe Creek. No cell threshold. Better analyses of the benthic microphytobenthos community may reveal more of this genus.

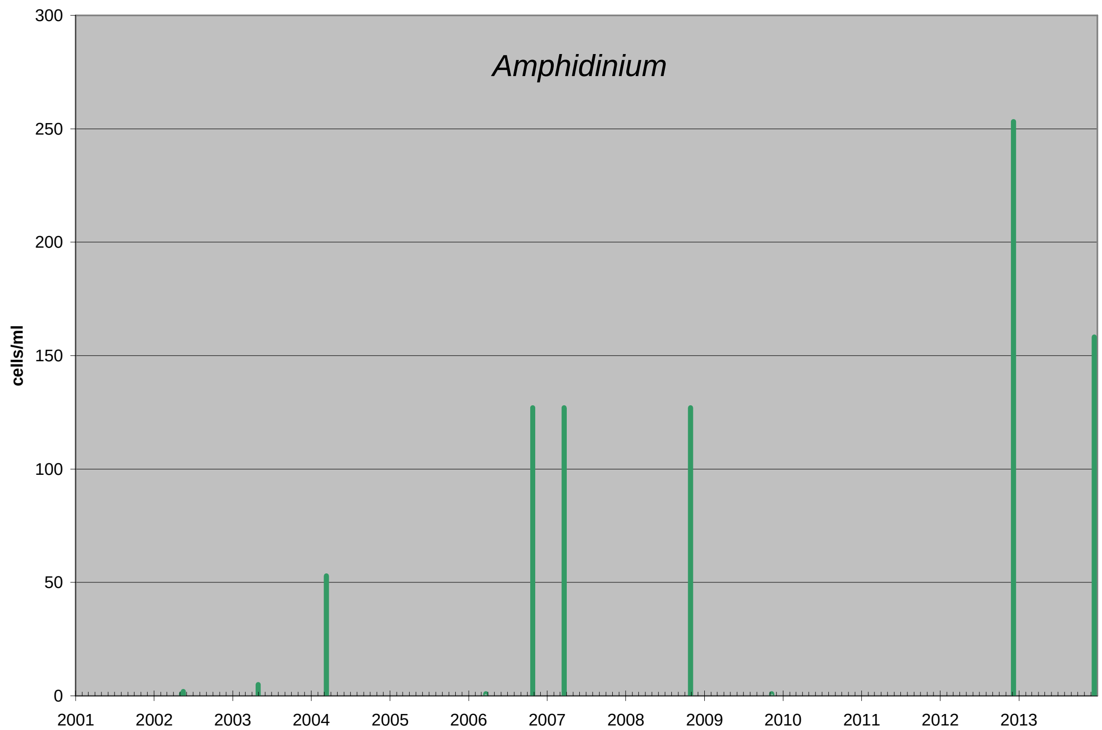

Figure 6.2.17 Occurrence of *Amphidinium sp.*in the Maryland Coastal Bays, 2001-2014.

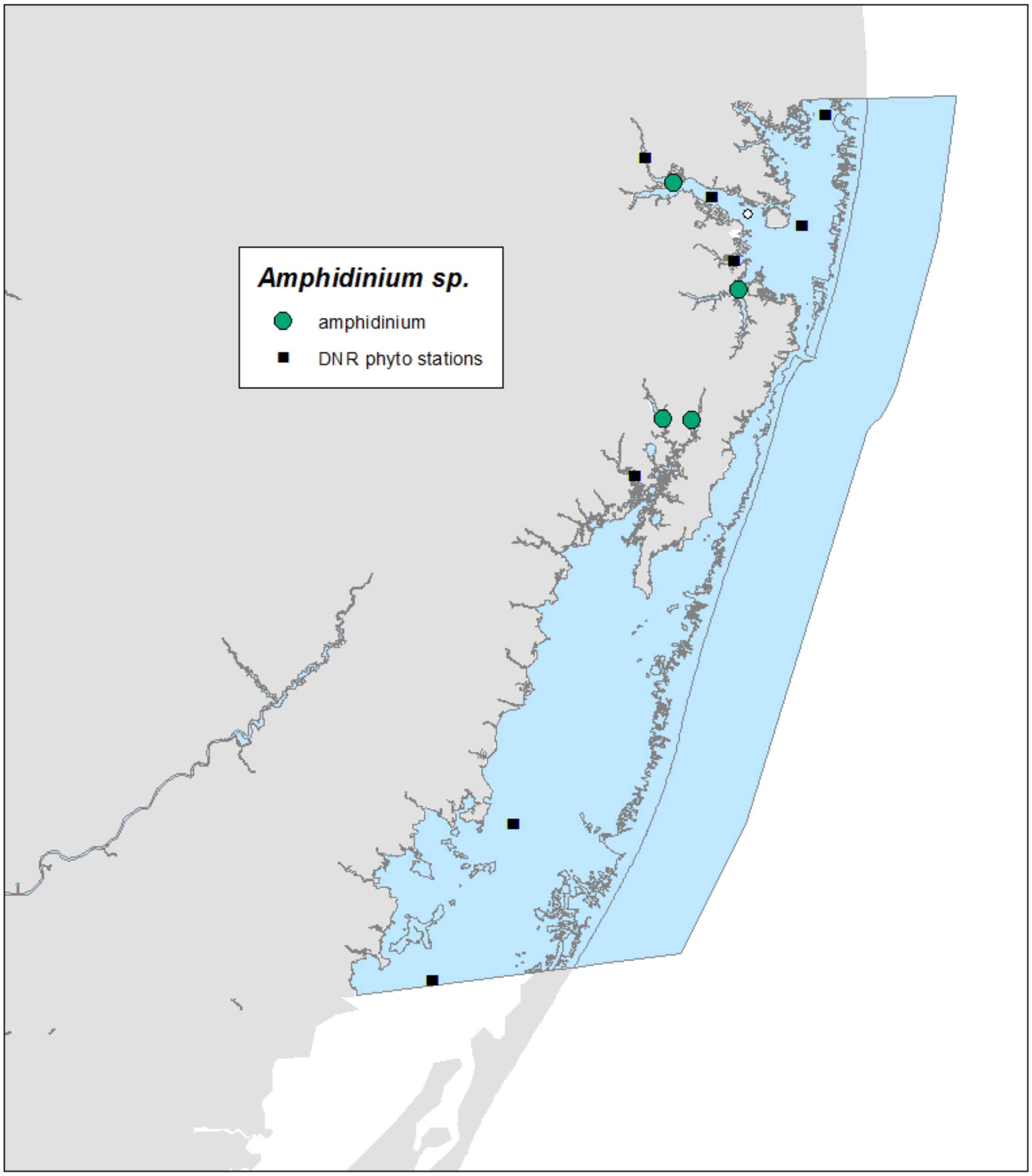

Figure 6.2.18 Distribution of *Amphidinium sp.* in the Maryland Coastal Bays, 2007-2014.

VIII. *Karlodinium micrum*

Karlodinium micrum may cause water to become discolored a reddish-brown and form Mahogany Tides. Mahogany tides may also severely reduce the amount of oxygen available to living resources at localized bloom sites. In large numbers, *Karlodinium micrum* will give the water a coffee color. *Prorocentrum minimum* tends to bloom earlier in the spring than *K. micrum* (late spring and early summer) although both species may occasionally be found blooming throughout the year on a local scale.

Karlodinium micrum is increasingly recognized for its ichthyotoxic effects in estuarine waters. Threshold levels for impacts on fish are considered 10,000 to 30,000 cells*ml^{-1}. *Karlodinium* *micrum,* is synonymous with *Gyrodinium galatheanum* Braarud and *Gymnodinium micrum,* and historically reported as *Gyrodinium estuariale* in Maryland. Recent work by Deeds et al. (2002) has demonstrated that Maryland isolates of the dinoflagellate from Chesapeake Bay produced toxins with hemolytic, cytotoxic and ichthyotoxic properties. Testing has not yet been conducted on samples from the Coastal Bays. Initial studies indicate *K. micrum* may produce sufficient toxin to result in fish mortality in the field at cell densities of 10,000 to 30,000 cells*ml^{-1} and above (Deeds et al. 2002, Goshorn et al. 2003). No human health effects have been associated with blooms of *K. micrum*.

2007 No bloom levels occurred.

2008 No bloom levels were detected.

2009 Blooms were found in Bishopville Prong in May (15,367 cells*ml^{-1}) and in the upper St Martin River in June (27,432 cells*ml^{-1}).

2010 No bloom levels were detected.

2011 Significant bloom during October in Bishopville Prong (58,801 cells*ml^{-1}) followed by lower abundance in November.

2012 No bloom levels were detected.

2013 No bloom levels were detected.

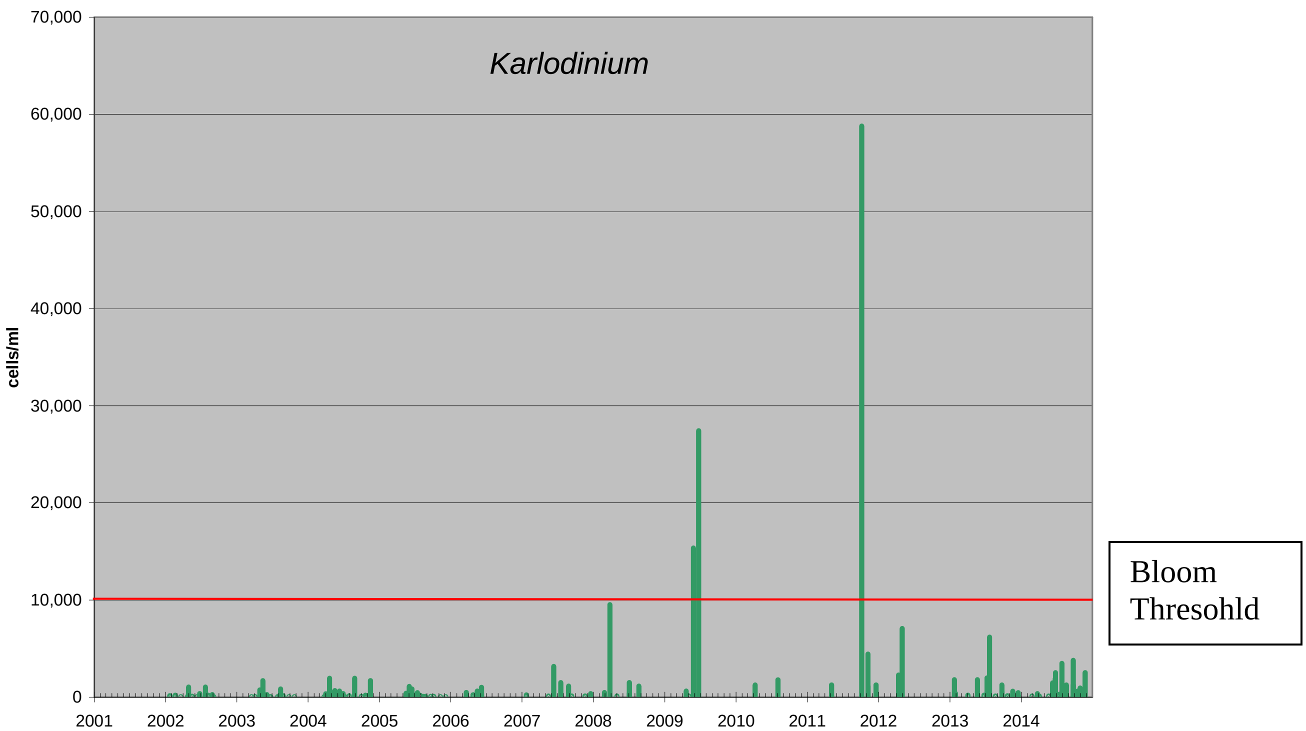

Figure 6.2.19 Occurrence of *Karlodinium veneficum* in the Maryland Coastal Bays between 2001-2014. Bloom threshold is 10,000 cells*ml^{-1}.

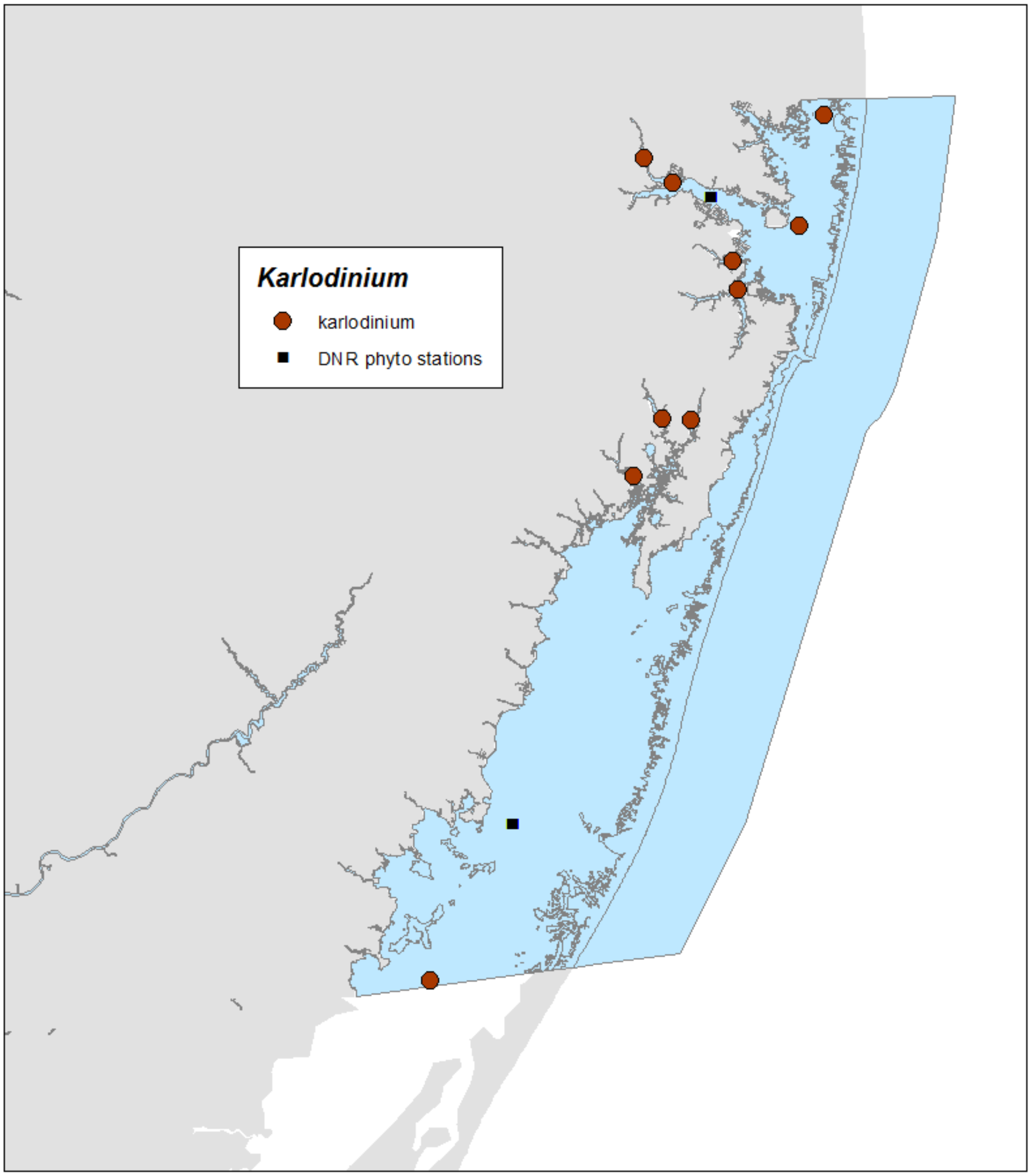

Figure 6.2.20 Distribution of *Karlodinium veneficum* in the Maryland Coastal Bays (2007-2014).

IX. Cyanobacteria

The winter of 2009 had blooms of cyanobacteria species in Trappe Creek including *Microcystis aeruginosa*, *Anabaena*, *Aphanizomenon* and *Oscillatoria*. Peaks in cyanobacteria abundance in 2009 is likely due to lower salinities resulting from higher rainfall that year (Figure 6.2.21). High levels of pico-cyanobacteria have been observed since a new microscope was implemented that allowed a greater magnification for small phytoplankton. Pico-cyanobacteria were very abundant in 2007 and 2008 (moderate in 2009-2012).

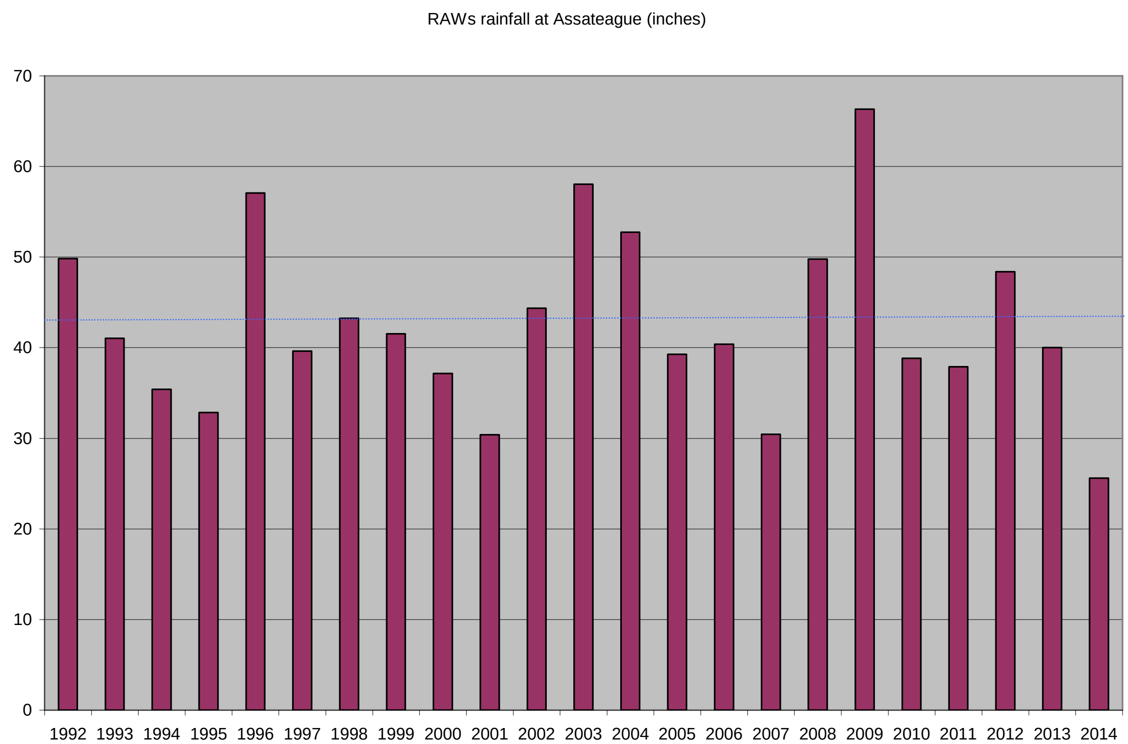

Figure 6.2.21 Rainfall record at Asssateague Island Remote Weather Station (RAWS) 1992-2014.

a. *Microcystis aeruginosa*

Microcystis is rarely seen in the Coastal Bays but was observed at significant bloom levels in 2009 in Trappe Creek. Toxic cyanophytes have been shown to affect a broad range of living resources. *Microcystis aeruginosa* is not unlike other possibly toxic phytoplankton species in that there may be a gradient of strain-related toxicity. Studies have shown negative effects on feeding to zooplankton by toxic and non-toxic *M. aeruginosa*. Fish kills have been attributed to cyanobacterial blooms and sub-lethal effects on fish can include reduced filtering rates, liver damage, modified ionic regulation and changes in behavior (Erickson et al. 1986, Rabergh et al. 1991).

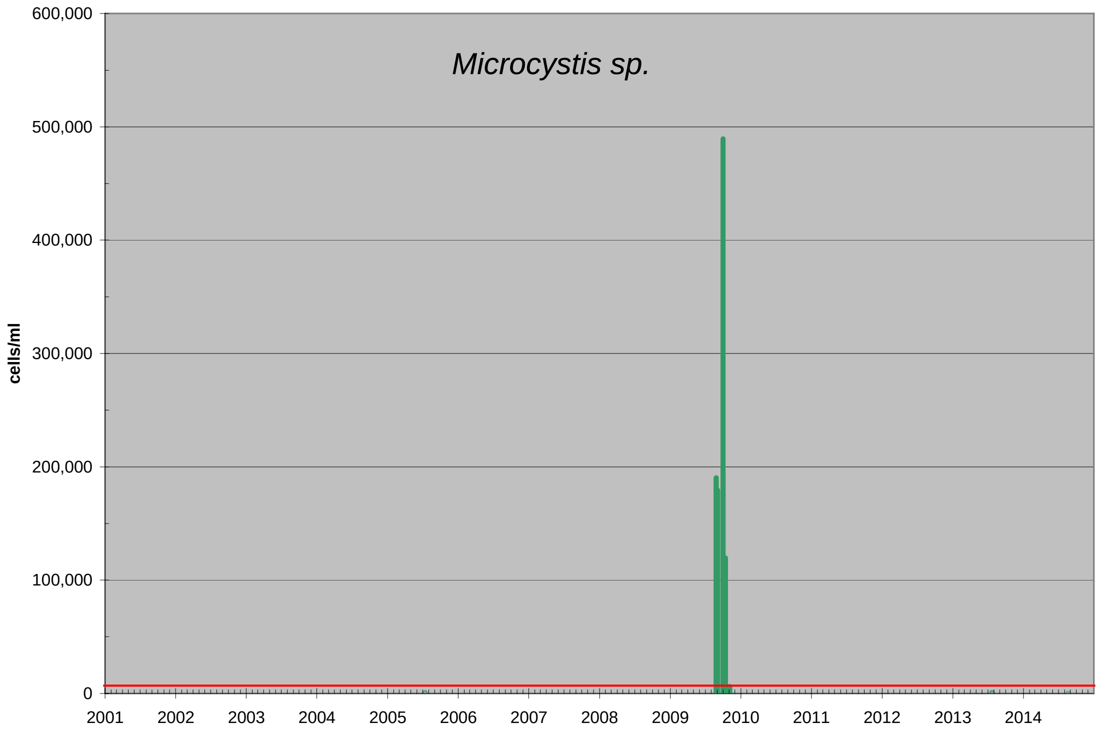

Figure 6.2.22 Occurrence of *Microcystis sp.* in the Maryland Coastal Bays, 2001-2014. Bloom threshold is 10,000 cells*ml^{-1} and potential toxin threshold exceedance may occur at 40,000 cells*ml^{-1}.

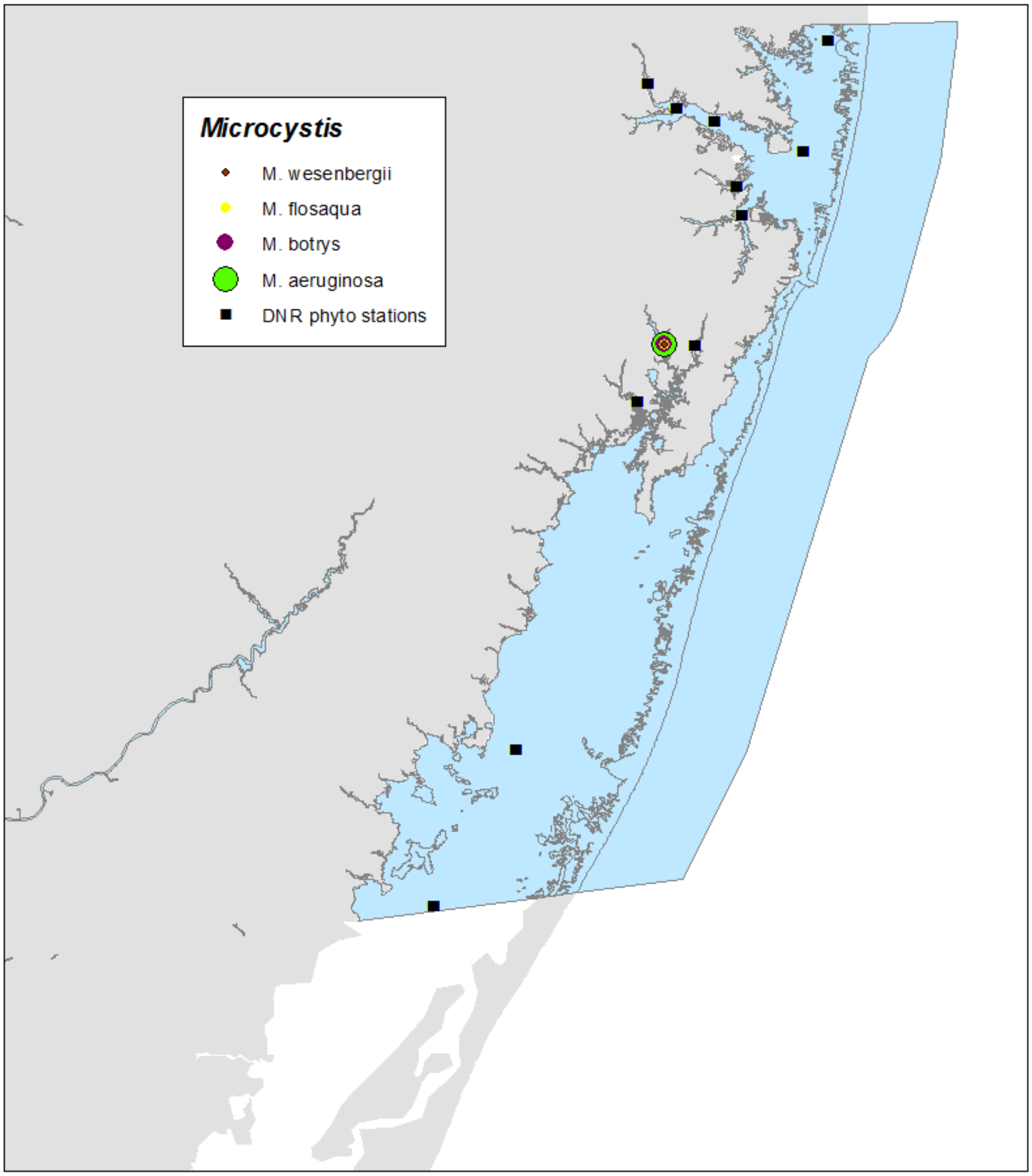

Figure 6.2.23 Distribution of *Microcystis species* in the Maryland Coastal Bays, 2007-2014.

2007, 2008 No blooms

2009 Bloom of *Microcystis aeruginosa* and *M. flosaguae* in Trappe Creek from late August to early November. Cell counts ranged from 101,346 to 489,500 cells* ml^{-1}.

2010-2013 No blooms.

b. <u>other Cyanophytes of Note</u>
Cyanophyte (bluegreen algae) concentrations in Bishopville Prong, Trappe Creek and Ayer's Creek have all shown declines from any pre-2000 phytoplankton sampling (Friedmen Chapter 3.3). Most species are not typically observed at the more saline stations in the coastal bays but in 2009 several species were detected at bloom levels in Trappe Creek (wet year and salinities were likely down).

Anabaena sp. were present in Trappe Creek in 2007 and bloom levels were observed in April 2009 and September/October (Figures 6.2.24 and 6.2.25). *Aphanizomenon sp.* also bloomed in Trappe Creek in 2009 (Figures 6.2.26 and 6.2.27). No toxin testing done. *Lyngbya sp* was not observed during the index time (2007-2013) but has been observed in 2005 and 2014 in the upper St. Martin River and Trappe Creek below bloom levels (Figures 6.2.28 and 6.2.29). *Oscillatoria sp.* was observed at blooms levels during September 2009 in Trappe Creek and St. Martin River (Figures 6.2.30 and 6.2.31).

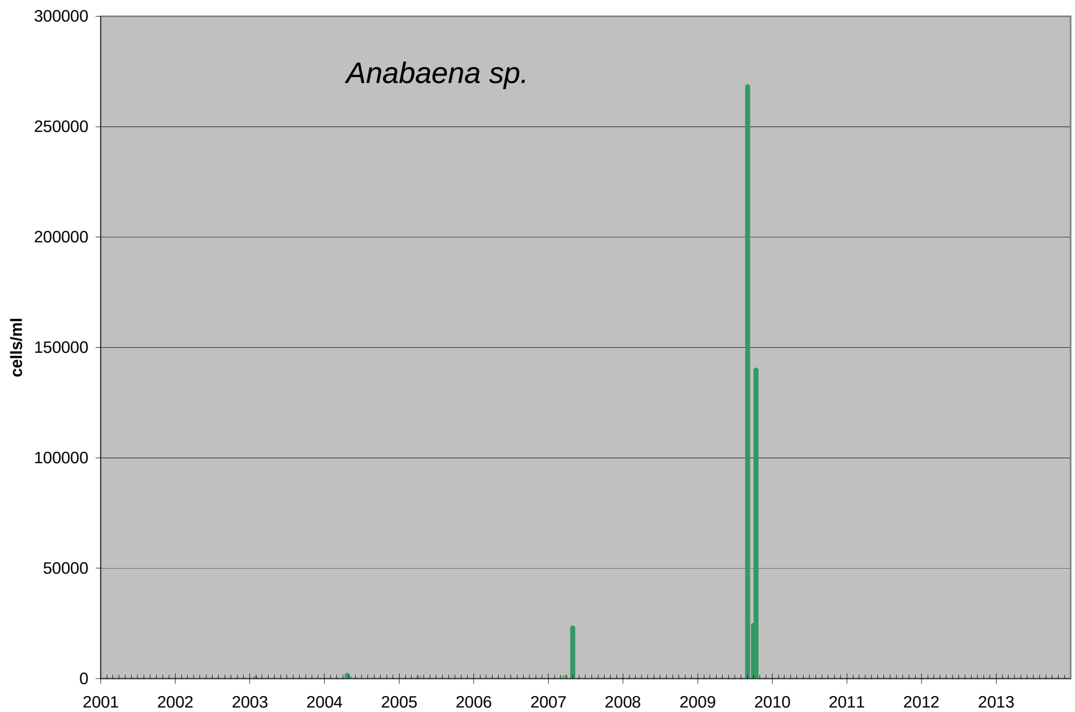

Figure 6.2.24 Occurrence of *Anabaena sp.* in the Maryland Coastal Bays, 2001-2014.

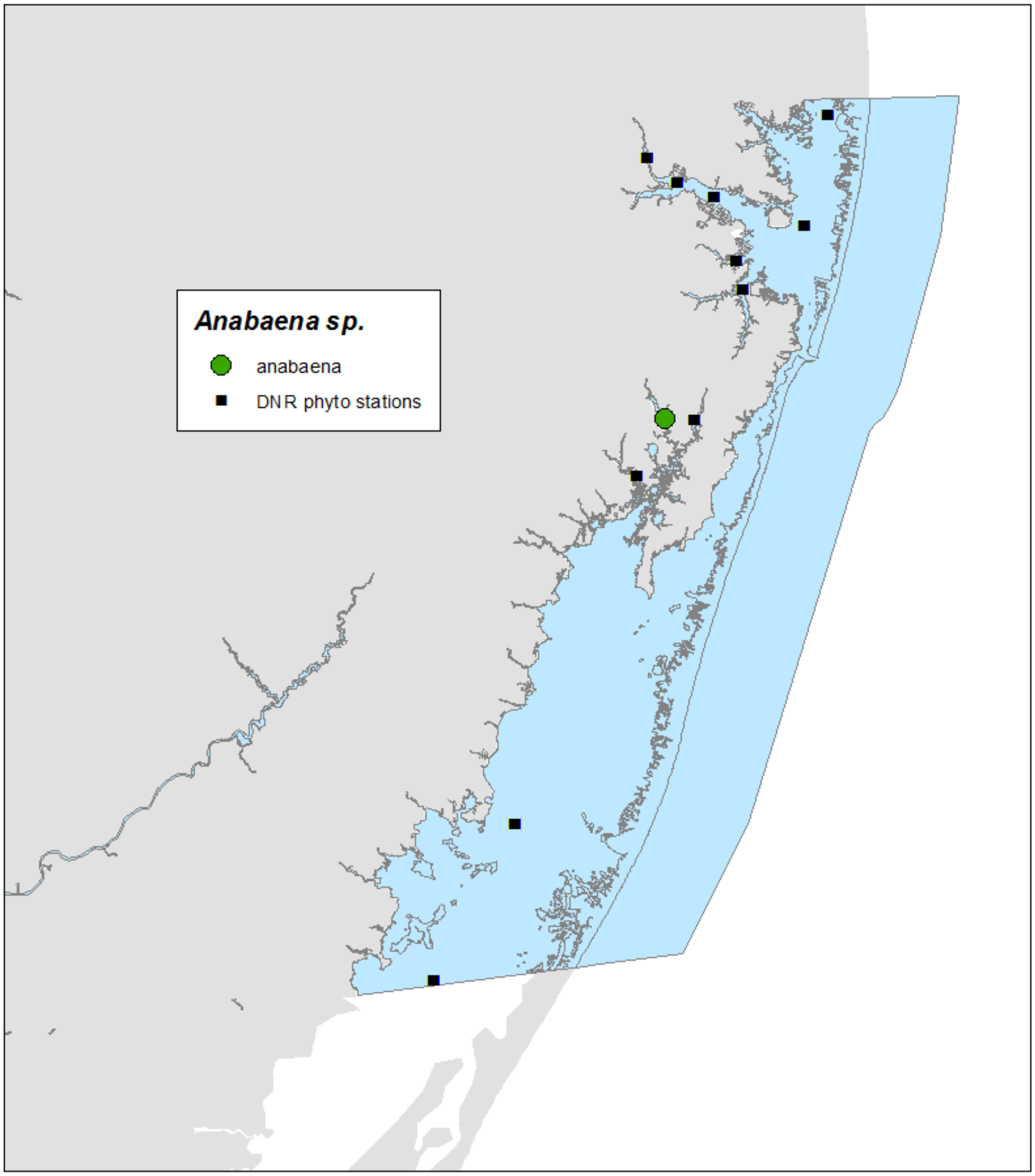

Figure 6.2.25 Distribution of *Anabaena sp.* in the Maryland Coastal Bays, 2007-2014.

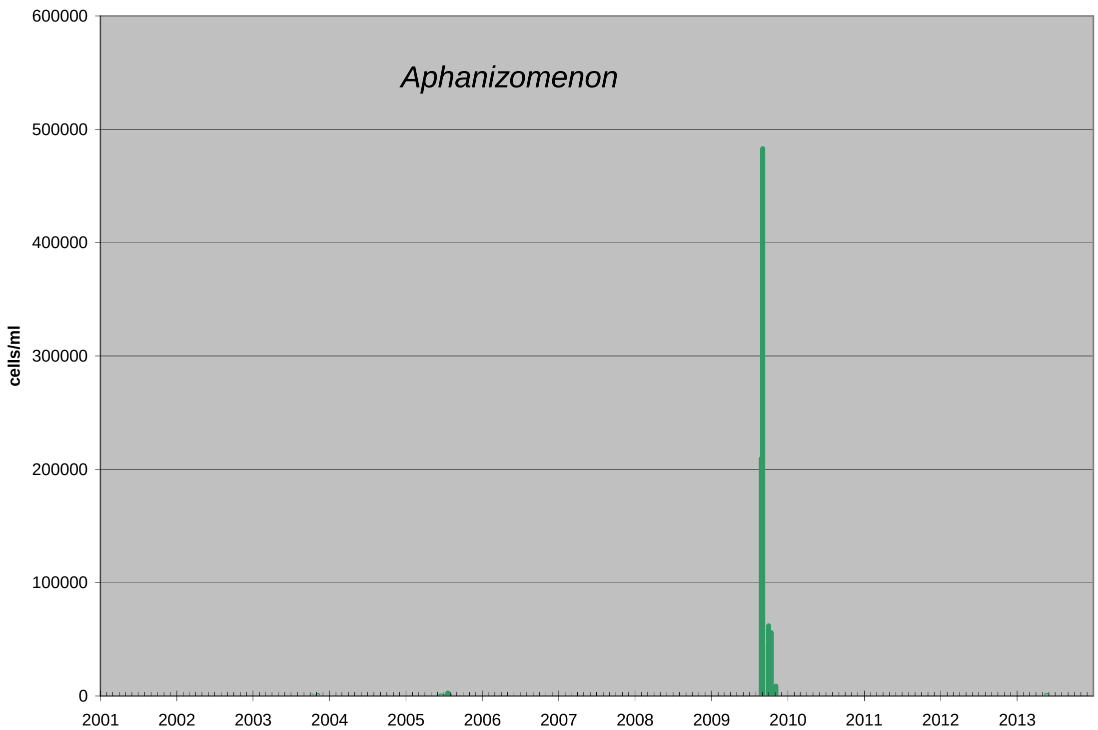

Figure 6.2.26 Occurrence of *Aphanizomenon* in the Maryland Coastal Bays from 2001-2014.

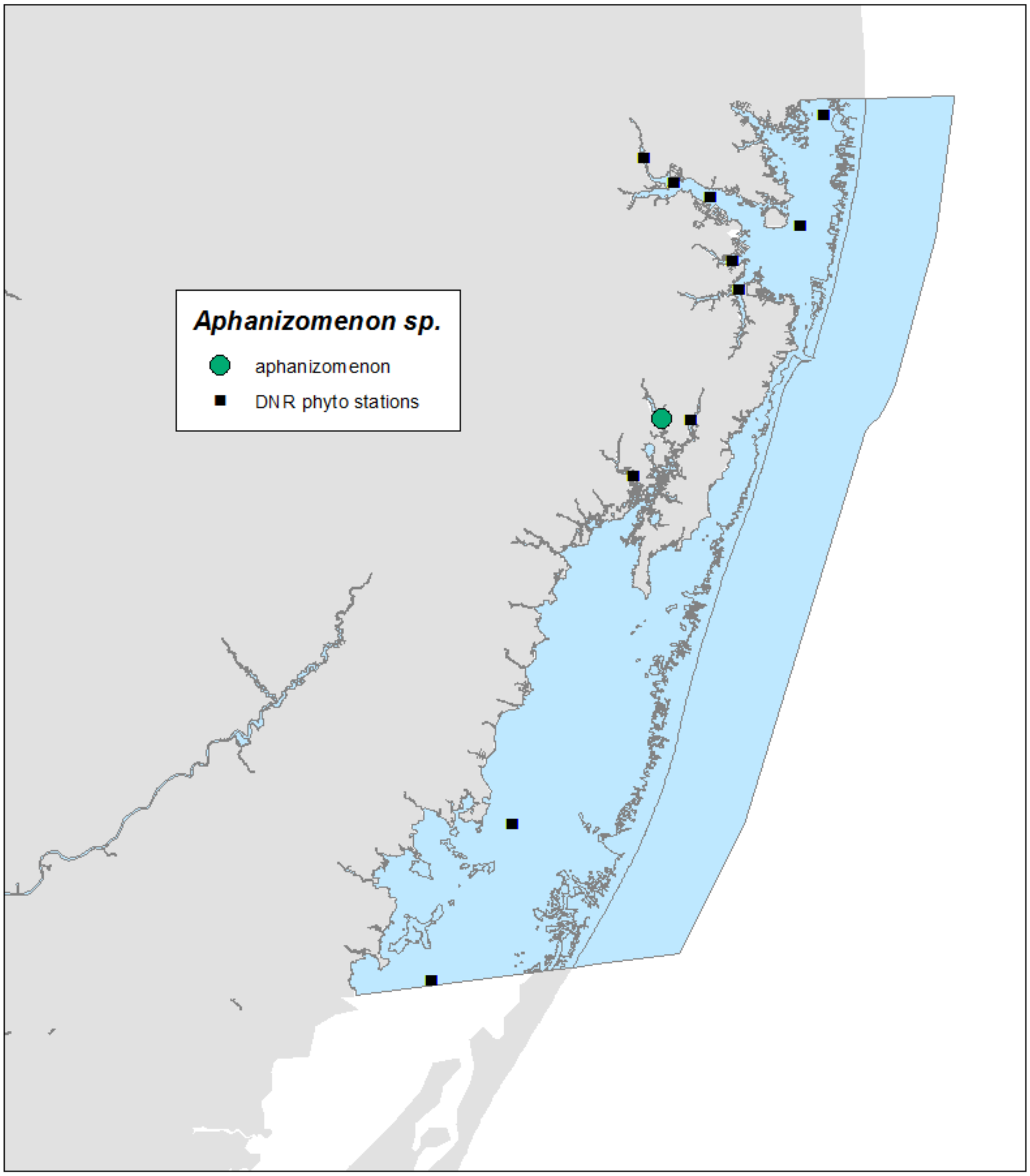

Figure 6.2.27 Distribution of *Aphanizomenon* in the Maryland Coastal Bays (2007-2014).

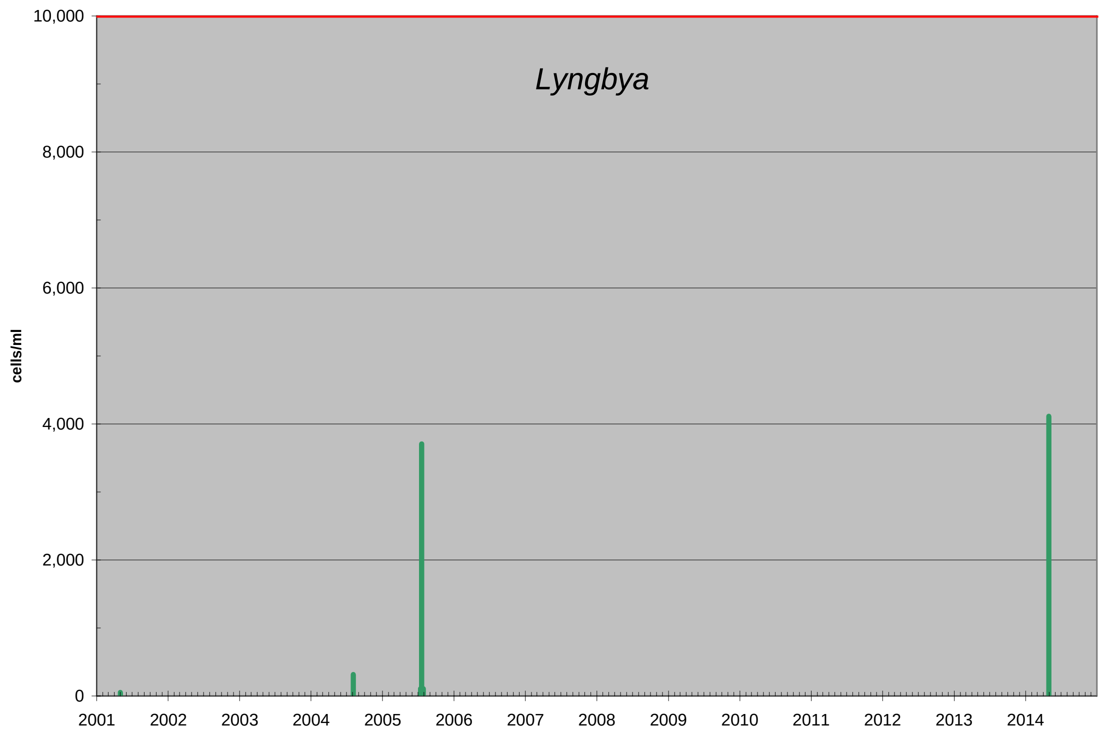

Figure 6.2.28 Occurrence of *Lygbya* in the Maryland Coastal Bays, 2001-2014.

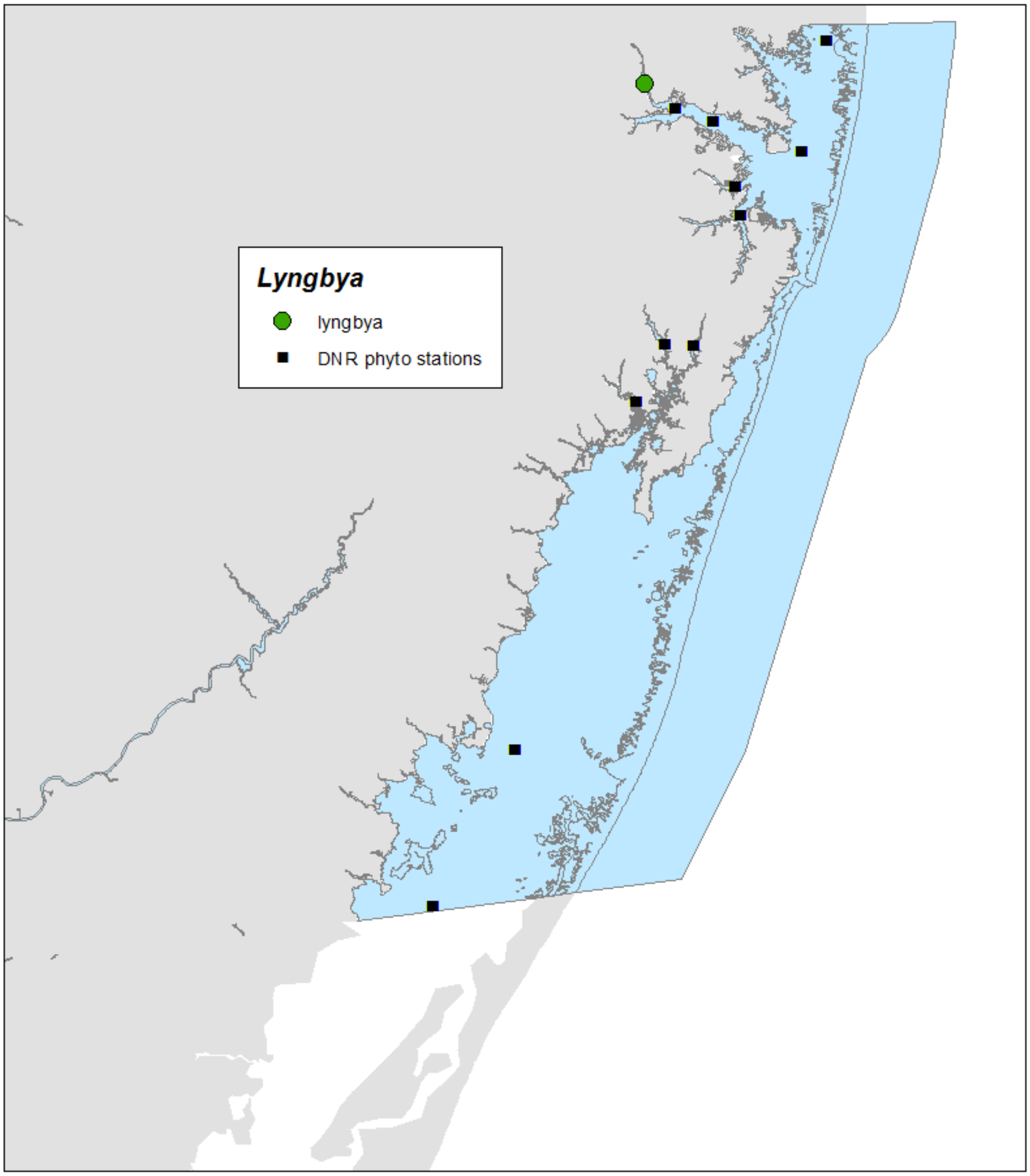

Figure 6.2.29 Distribution of *Lyngbya* in the Maryland Coastal Bays (2007-2014).

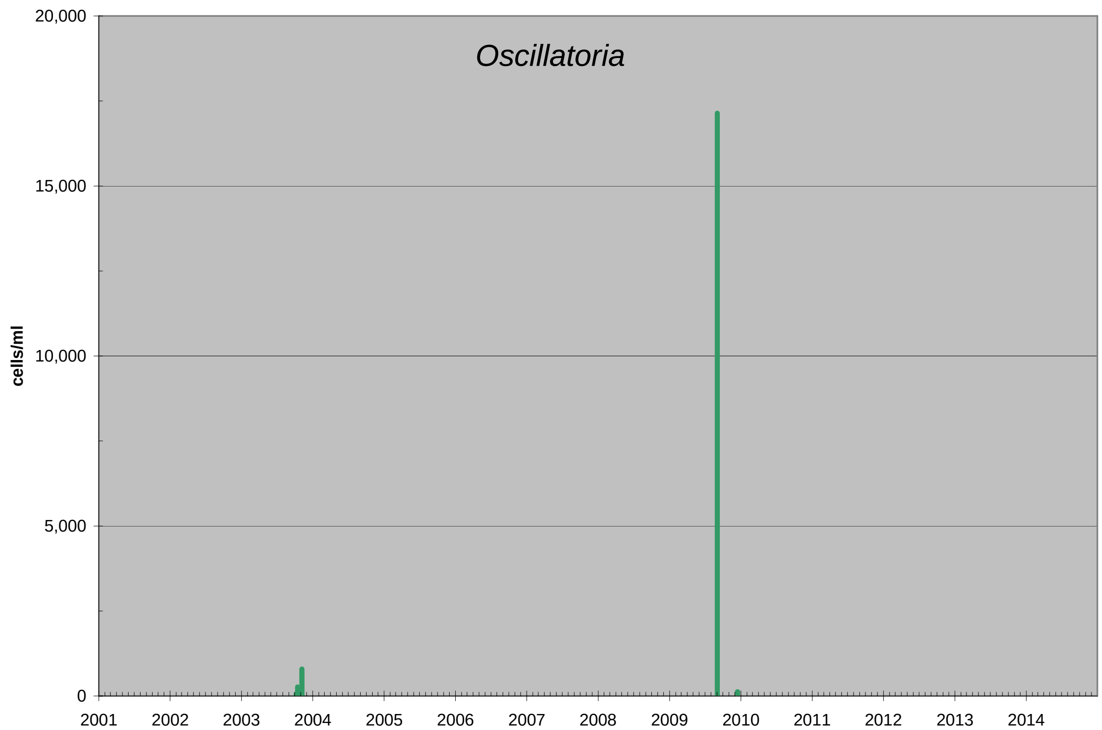

Figure 6.2.30 Occurrence of *Oscillatoria* in the Maryland Coastal Bays, 2001-2014.

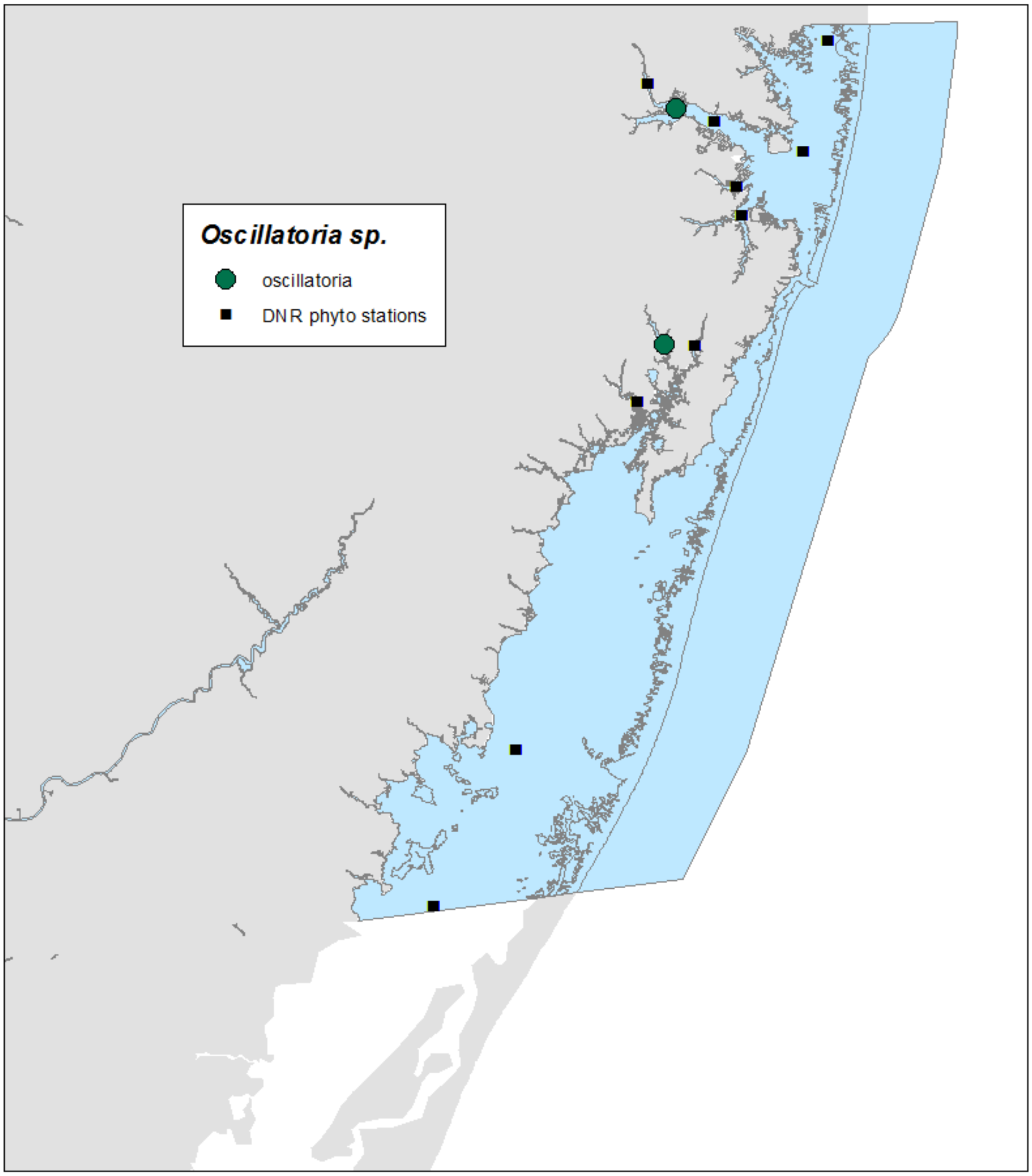

Figure 6.2.31 Distribution of *Oscillatoria* in the Maryland Coastal Bays (2007-2014).

b. <u>other Cyanophytes: Pico-cyanobacteria</u>
High levels of picoplankton have been observed since a new microscope was implemented in 2006 that allowed a greater magnification for small phytoplankton. Pico-cyanobacteria were abundant in 2007 and 2008 with highest concentrations (> one million cells* ml^{-1}) were observed in St Martin River, Trappe Creek, Ayers Creek and Marshal Creek. Concentrations of pico-cyanobacteria were moderate during 2009-2012. Positive identification of such small organisms is not possible using light microscopy alone. Further study is needed to identify the organism(s).

2007 Bloom levels exceeded two million cells*ml^{-1}in Trappe during September (bloomed from May to Sept). Blooms were also observed in Ayres Creek (786,587 cells*ml^{-1} in May), Marshal Creek and the St Martin River (July-October).

2008 Bloom levels exceeded one million cells*ml^{-1}.in Ayres Creek in June. Blooms also observed in Trappe Creek and St Martin River as well as Chincoteague (July 29 421,640 cells*ml^{-1}) and Assawoman (July 28- 589,280 cells*ml^{-1}) Bays.

2009 Blooms were found in Marshal Creek (447,040 cells*ml^{-1}) during June and in the upper St Martin River in September (497,840 cells*ml^{-1}).

2010 No bloom levels were detected.

2011 Significant bloom during April (923,036 cells*ml^{-1}) and June in Ayers Creek (409,346 cells*ml^{-1}) and in elevated in Trappe Creek, Marshall Creek and Bishopville Prong.

2012 No bloom levels were detected.

2013 No blooms were detected.

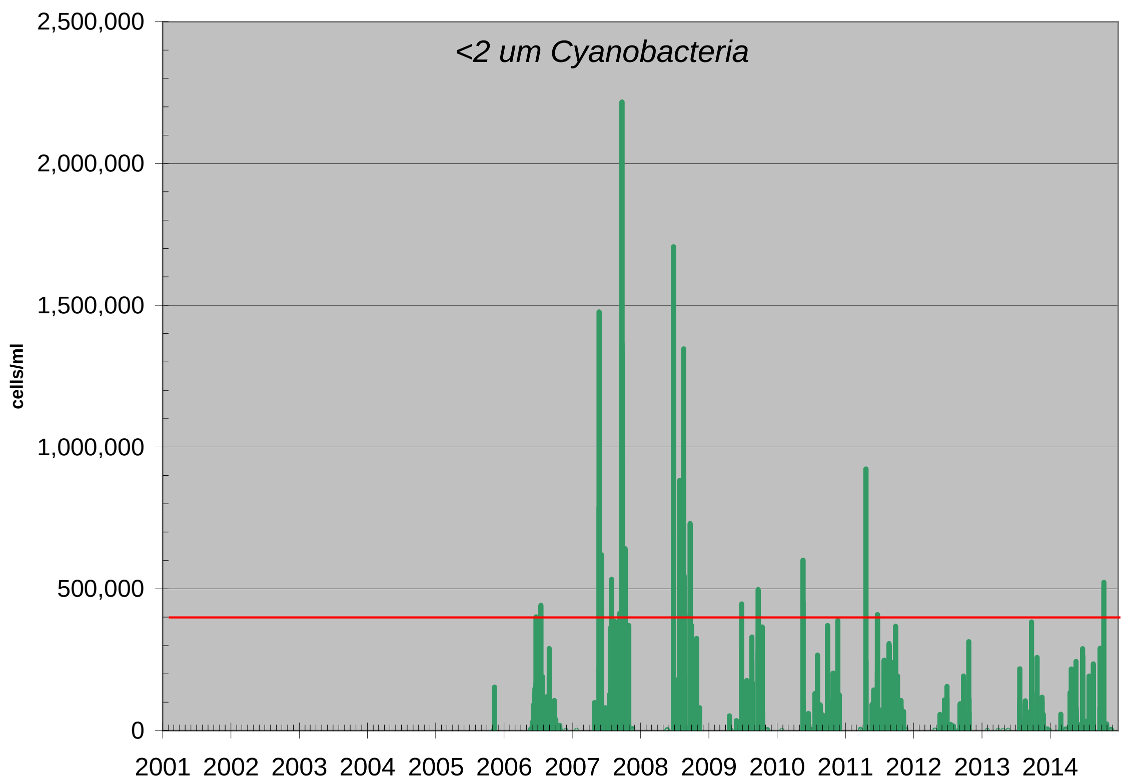

Figure 6.2.32 Occurrence of pico-cyanobacteria *(<2*µM) in the Maryland Coastal Bays, 2007-2014.

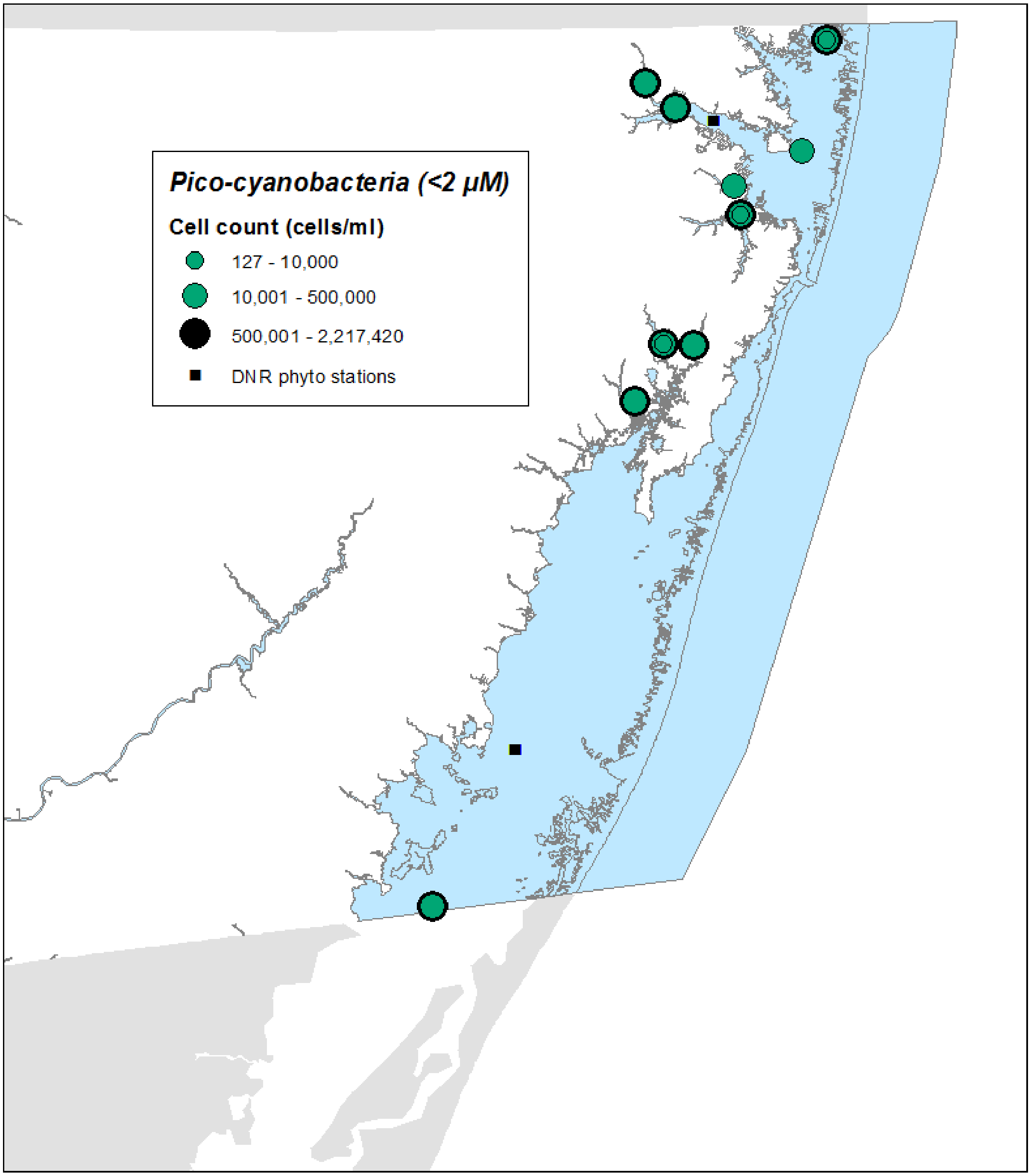

Figure 6.2.33 Distribution of pico-*cyanobacteria* (<2µM) in the Maryland Coastal Bays (2007-2014).

X. <u>*Gonyaulax*</u>

Gonyaulax is a genus of Dinoflagellates. *Gonyaulax spinifera* has been related to production of Yessotoxins (YTXs), a group of structurally related polyether toxins, which can accumulate in shellfish and can produce symptoms similar to those produced by Paralytic Shellfish Poisoning (PSP) toxins. All species are marine, except for one freshwater species *Gonyaulax apiculata.* It previously included several species, which are now considered to belong to a separate genus, e.g. *Gonyaulax tamarensis* (now: *Alexandrium tamarense*).

Gonyaulax is observed infrequently in the Maryland Coastal Bays. Highest concentration was found in Bishopville Prong on the upper St Martin River during June 2004 (2,120 cells*ml^{-1}) and Trappe Creek in 2003 (864 cells*ml^{-1}). During 2007 to 2013 it was seldom recorded and only in the Bishopville Prong.

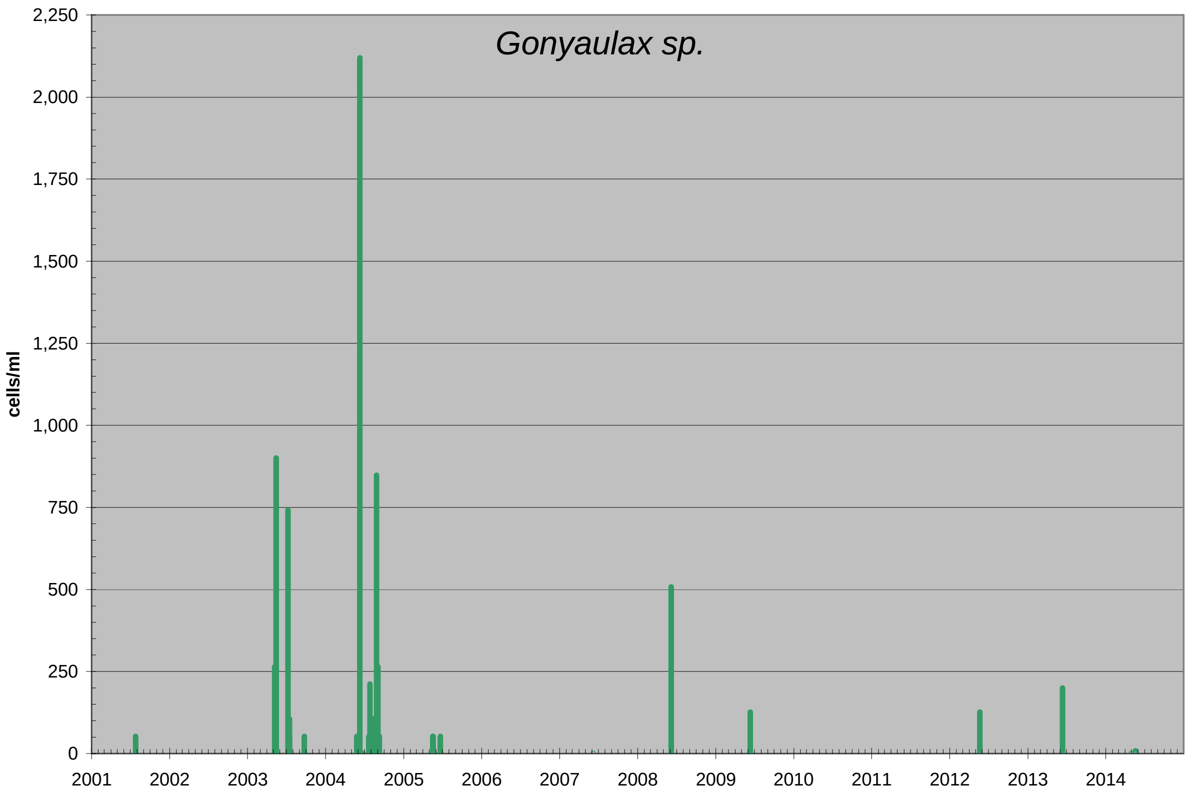

Figure 6.2.34 Occurrence of *Gonyaulax* in the Maryland Coastal Bays, 2001-2014.

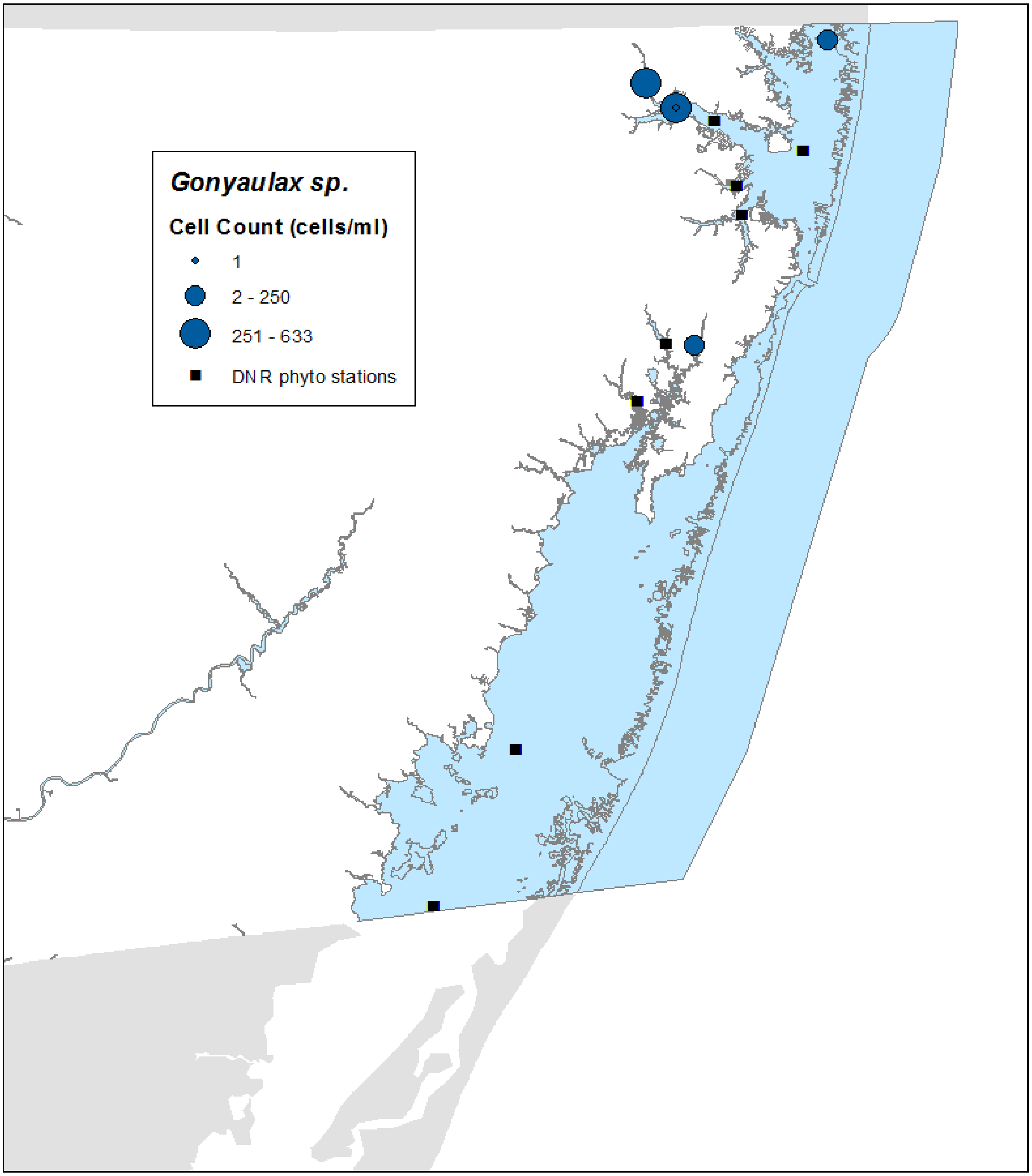

Figure 6.2.35 Distribution of *Gonyaulax* in the Maryland Coastal Bays (2007-2013).

XI. <u>Ecosystem disruptive HAB: macroalgae</u>

Macroalgae are considered harmful by the National Oceanographic and Atmospheric Administration (NOAA) when they produce dense overgrowth in localized areas, such as coastal embayments, receiving excessive nutrient loads. These accumulations can be so high as to cover the bottom, excluding other life. Also, when such large masses of macroalgae begin to die, excessive oxygen consumption associated with the decomposition process can rob the water of oxygen (Bushaw-Newton and Sellner 1999). Two genera of macroalgae are believed to qualify as HABs under NOAA's definition in specific areas of the Coastal Bays. *Gracilaria* in Turville Creek was so dense in 1999-2001 that it caused the fishery monitoring program to relocate a 25-plus year monitoring station. This system is prone to low dissolved oxygen levels that are probably influenced by these blooms. Furthermore, Total Maximum Daily Load models of this system were insufficient in predicting the low dissolved oxygen, likely because they failed to incorporate primary producers other that phytoplankton. *Chaetomorpha* levels in Chincoteague Bay were so dense during 1998-2001 that it is believed to have impacted scallop restoration efforts and seagrass density in some areas (R.Orth and M. Tarnowski, personal communication).

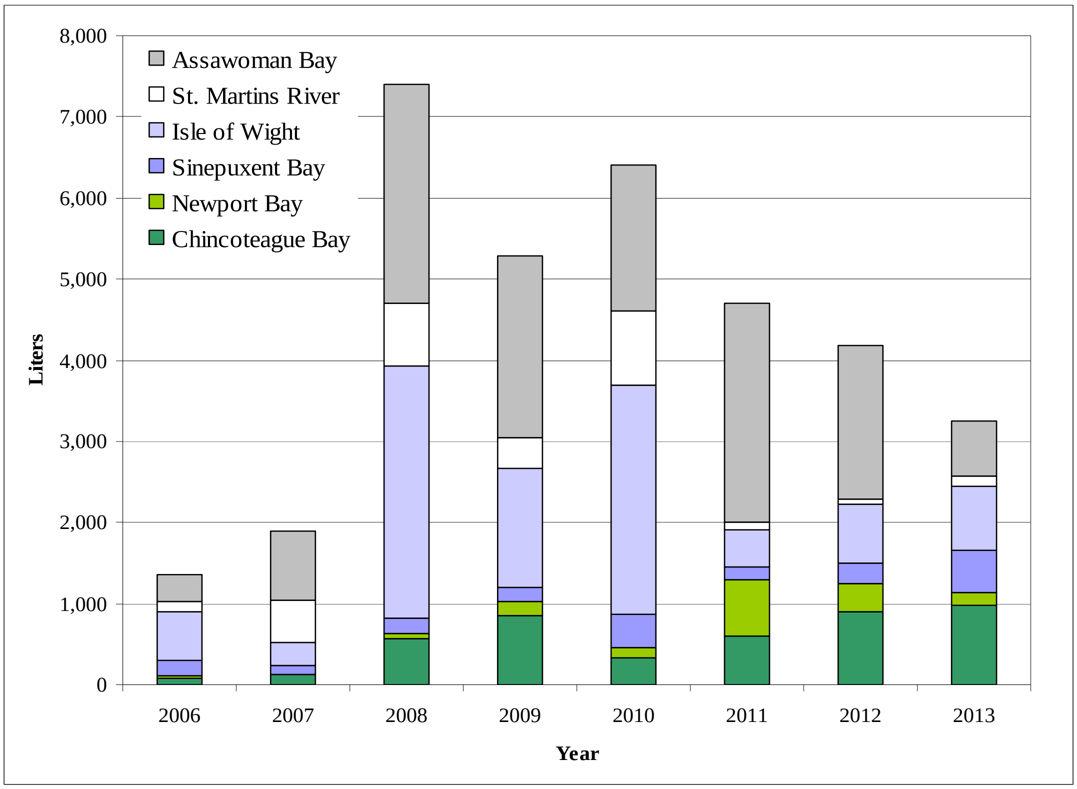

Figure 6.2.36 Macroalgae abundance by area and year from the Coastal Bays Fisheries Investigation Trawl and Beach Seine Survey (trawl n=140/year and beach seine n = 38/year). For more information please refer to Chapter 6.3 of this assessment.

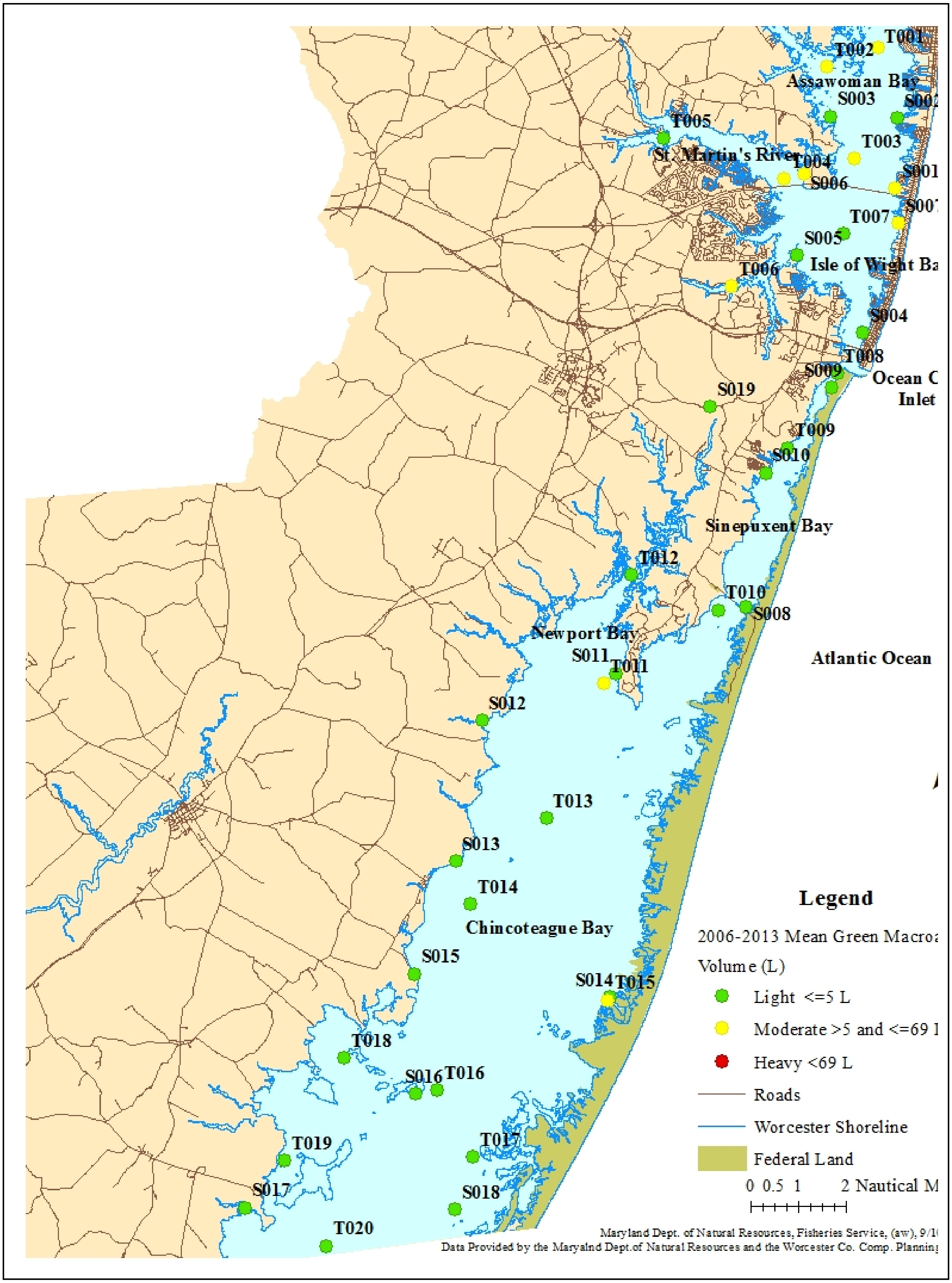

Figure 6.2.37a Distribution of green macroalgae in the Maryland Coastal Bays 2006-2013.

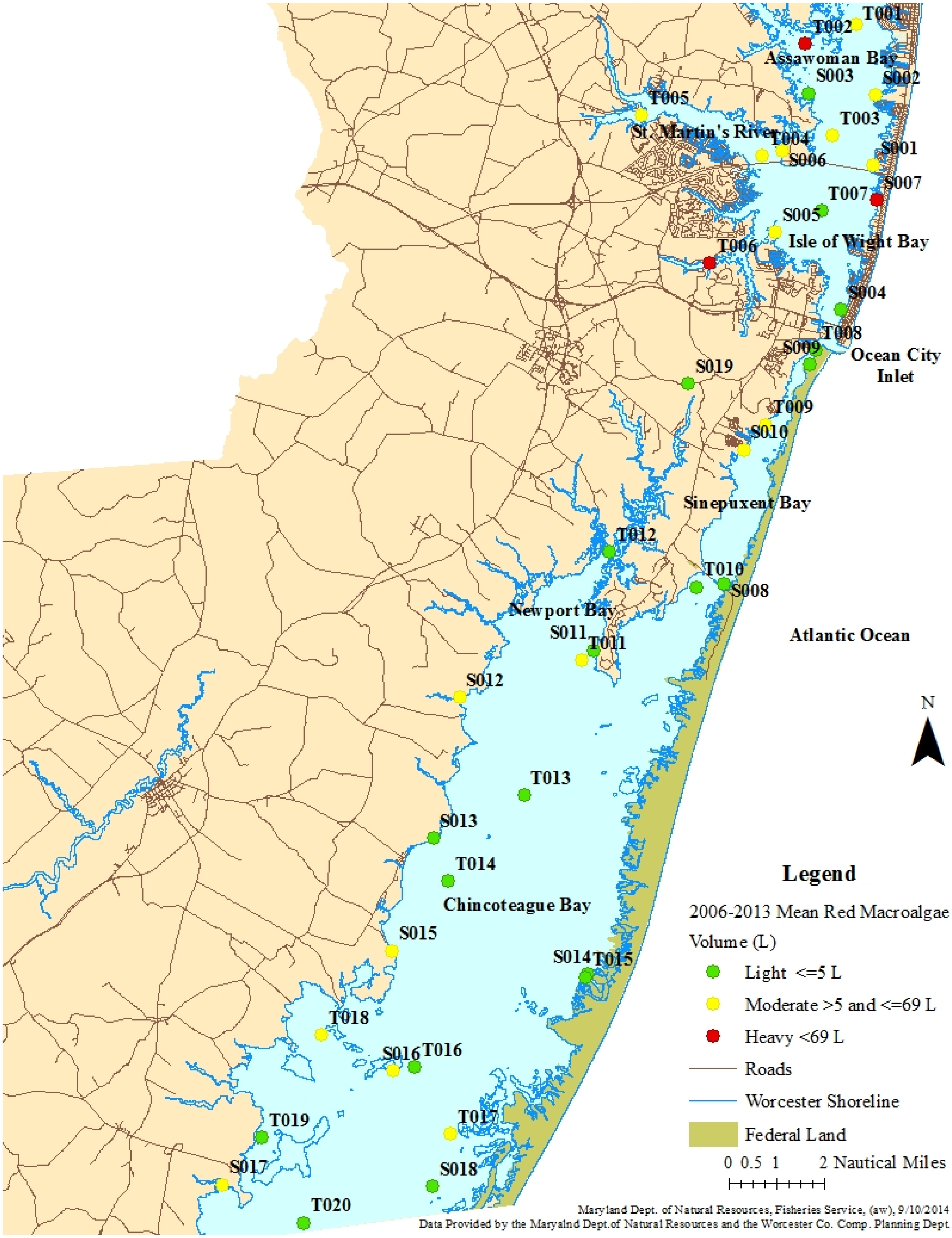

Figure 6.2.37b Distribution of red macroalgae in the Maryland Coastal Bays 2006-2013.

XII. <u>Ecosystem Disruptive HAB: *Heterocapsa spp*</u>.

The high biomass blooms of *Heterocapsa spp.* allows new nutrients delivered to the bays in the winter (generally a time of limited primary production) to be maintained in the bays and recycled for dpring blooms. *Heterocapsa rotunda* is more prevelant in the Coastal Bays than *H. triquetra*. *H. rotunda* showed a significant bloom in 2008 (Figure 6.2.38) and *H. triquetra* in 2010 (Figure 6.2.39 and Figure 6.2.40).

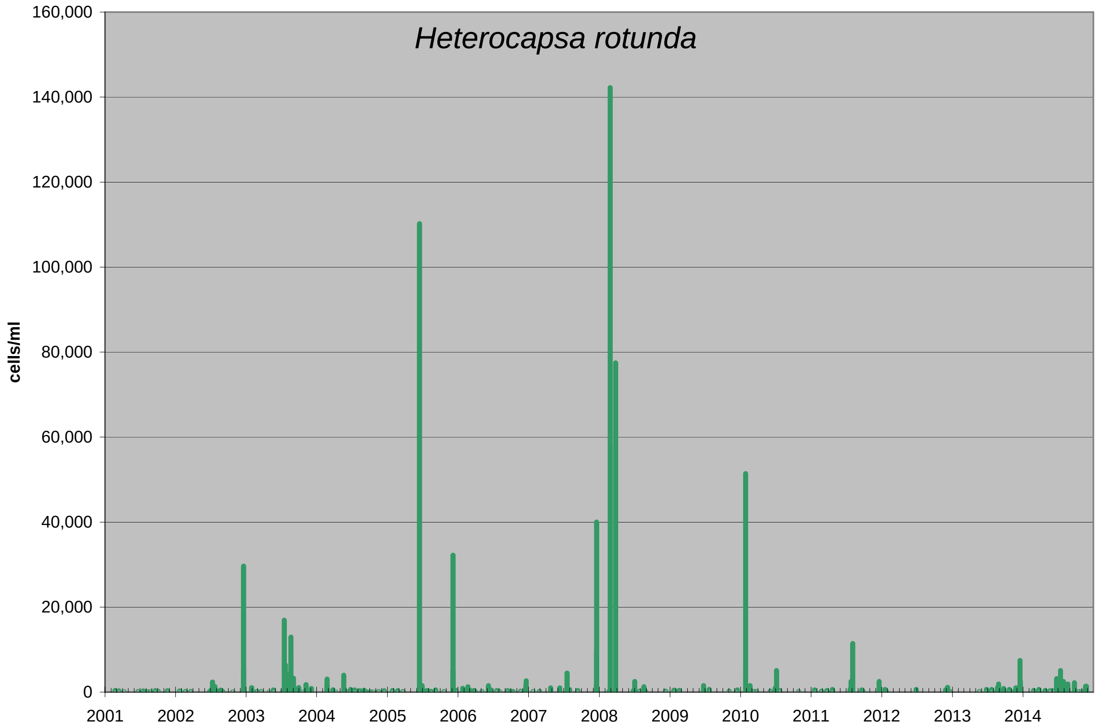

Figure 6.2.38 Occurrence of *Heterocapsa rotunda* in the Maryland Coastal Bays, 2001-2014.

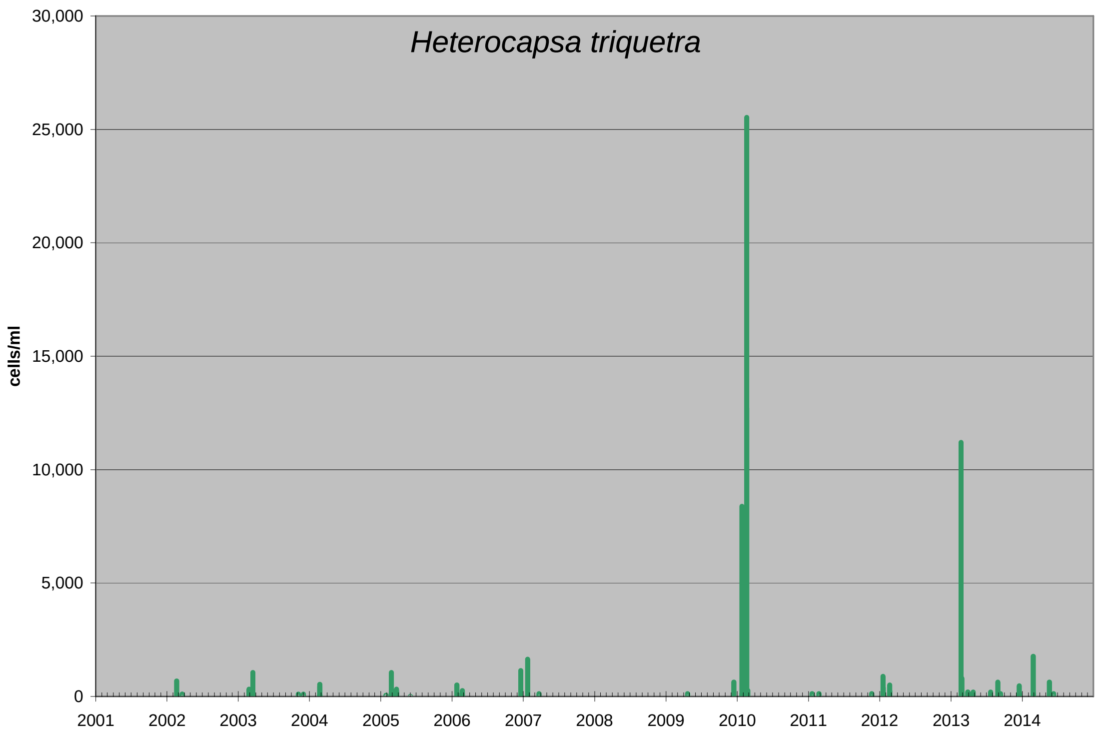

Figure 6.2.39 Occurrence of *Heterocapsa triquetra* in the Maryland Coastal Bays, 2001-2014.

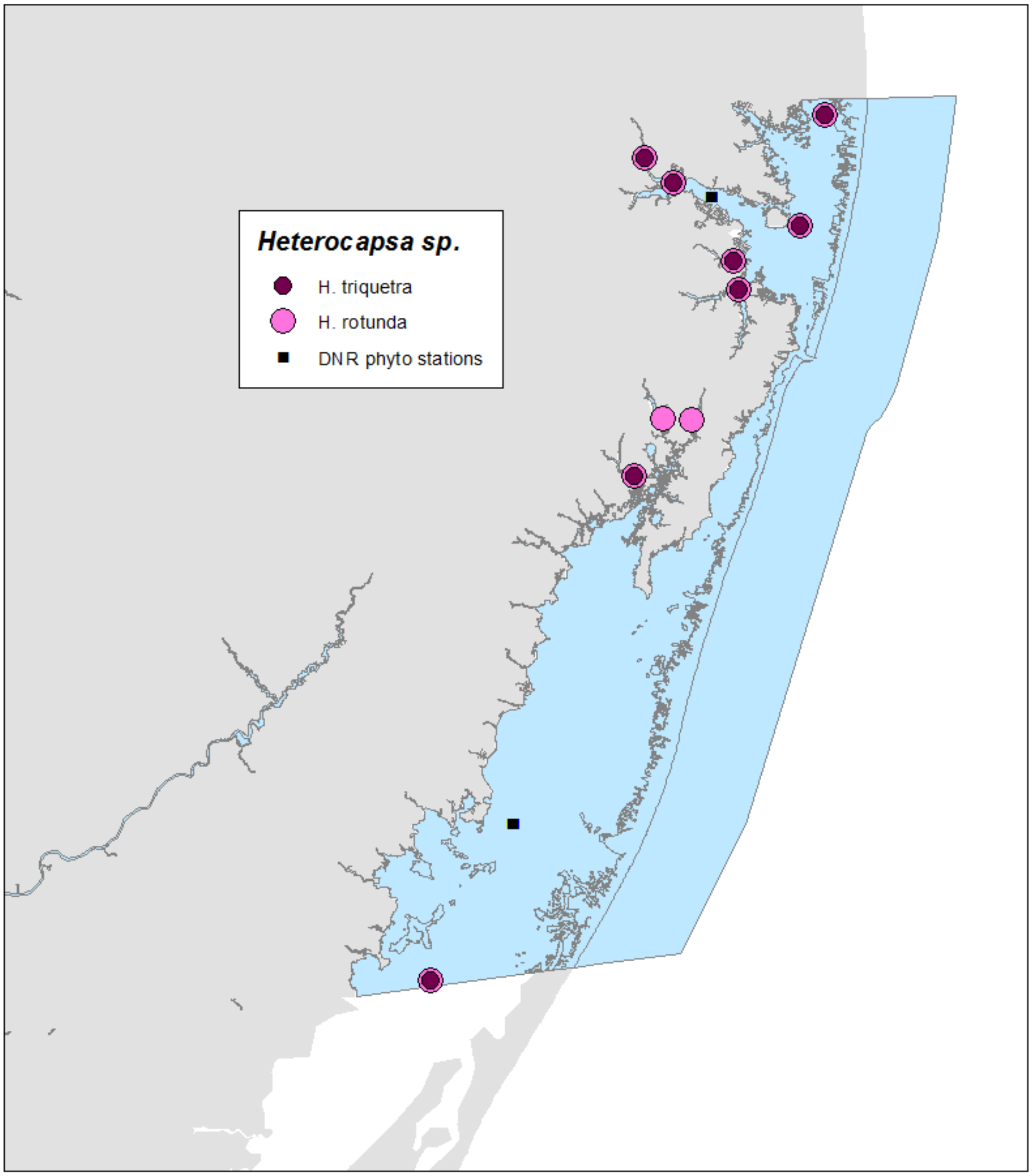

Figure 6.2.40 Distritubtion of *Heterocapsa sp* in the Maryland Coastal Bays (2007-2013).

XIII. Ecosystem Disruptive HAB: *Akashiwo sanguienum*

Harmful affects from this non-toxic dinoflagellate were first reported during a massive red tide (chlorophyll levels between 50-200 μg/L) that occurred November 2007 in Monterey Bay, California. Although this red tide bloom was ostensibly nontoxic, it was very harmful, causing unprecedented beach stranding of live and dead seabirds. Affected birds had a slimy yellow-green material on their feathers, which were saturated with water, and they were severely hypothermic. It was determined that foam containing surfactant-like proteins, derived from organic matter of the red tide, coated their feathers and neutralized natural water repellency and insulation This is the first documented case of its kind, but previous similar events worldwide may have gone undetected.

Akashiwo has been detected in the Coastal Bays with the highest concentrations found in the winter of 2013 in Manklin and Turville creeks (Figure 6.2.41s and 6.2.42). More offshore phytoplankton data would be useful to determine if blooms occur in the coastal Atlantic.

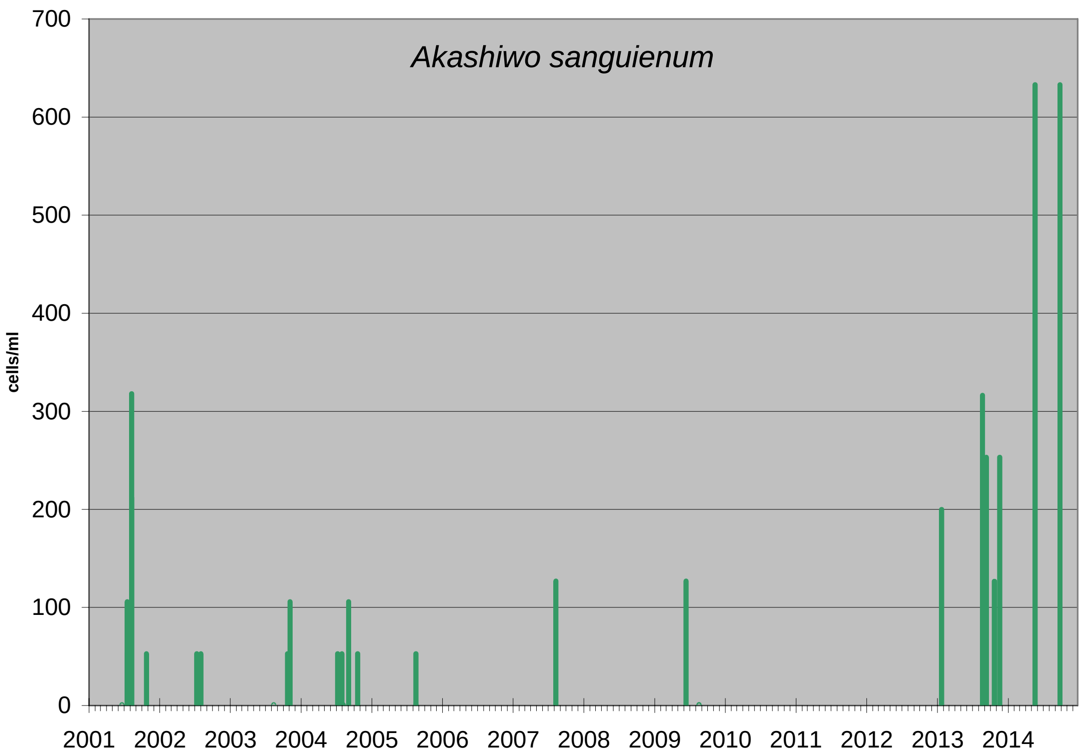

Figure 6.2.41 Occurrence of *Akashiwo seanguienum* in the Maryland Coastal Bays, 2001-2014.

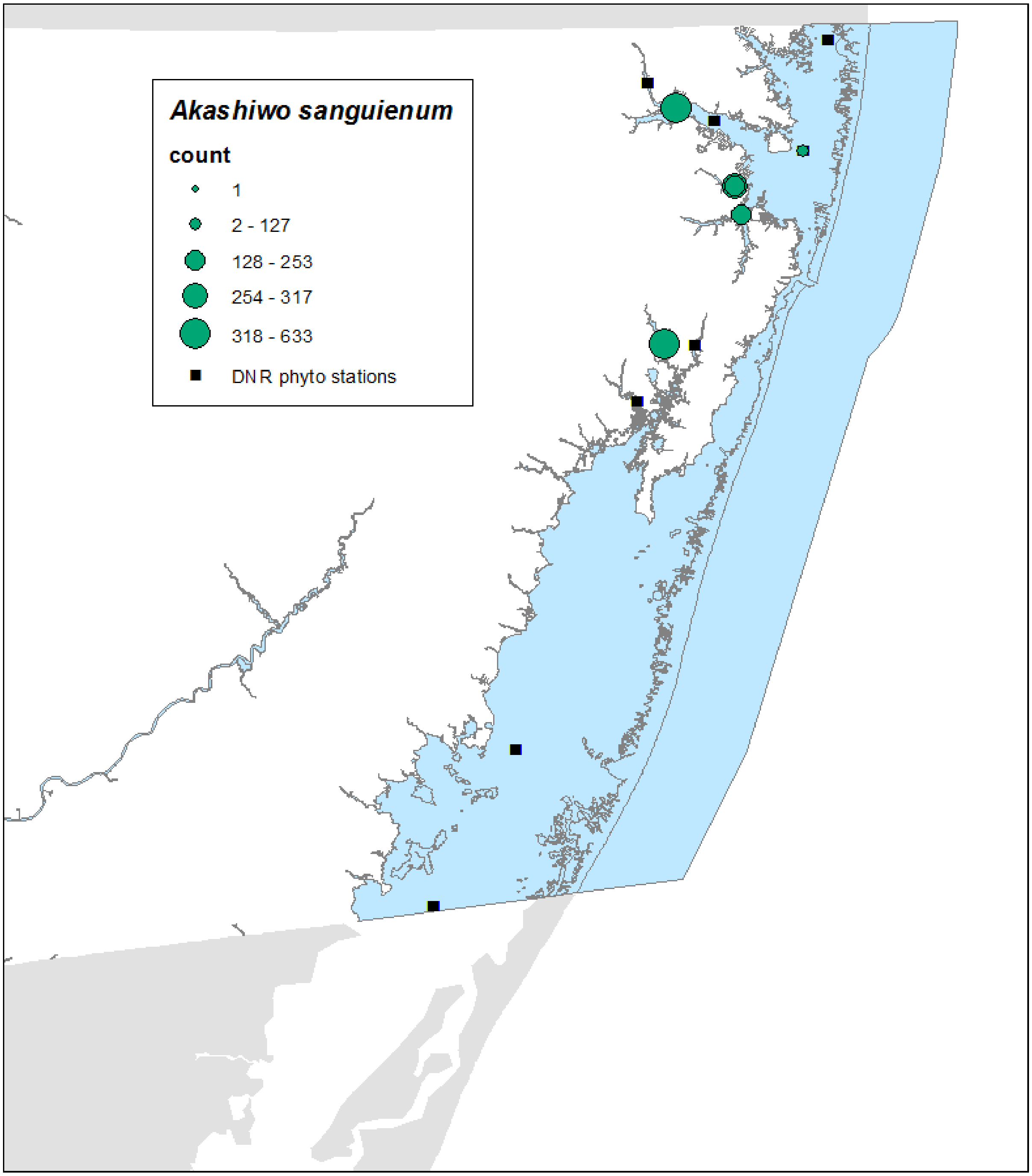

Figure 6.2.42 Distritubtion of *Akashiwo seanguienum* in the MD Coastal Bays (2007-2014).

Summary
Approximately 5% of the phytoplankton community identified in Maryland's Coastal Bays, represent HAB species. HABs are recognized for their potentially toxic properties as well as their ability to produce large blooms negatively affecting light and dissolved oxygen resources. Brown tide (*A. anophagefferens*) has been the most widespread and prolific species in the area in recent years producing growth impacts to juvenile clams in test studies and potential impacts to seagrass distribution and growth (see Chapter 6.1). Little toxic activity has been detected among the Coastal Bays phytoplankton such as *Dinophysis acuminate*, Raphidophyte species and recently some cyanobacteria species. However, other species such as *Pseudo-nitzschia seriata*, *Prorocentrum minimum*, *Pfiesteria piscicida*, and *Karlodinium micrum* have produced positive toxic bioassays or generated detectable toxins in the Chesapeake Bay. *Pfiesteria piscicida* was retrospectively considered as the likely causative organism in a large historical fish kill on the Indian River, Delaware. Similarly *Chloromorum toxicum* (formerly *Chattonella* cf. *verruculosa*) was implicated in a large fish kill and persistent brevetoxins detected in Delaware's Rehobeth Bay during 2000. Large increases in macroalgal may be evidence of a seagrass dominant system balancing on the edge of a eutrophic state. Tracking HAB species diversity, abundance, distribution and toxic activity through time provides important indicators of environmental change for the Coastal Bays.

Thirteen potentially harmful algae species have been identified as threats in the Maryland Coastal Bays including *Aureococcus anophagefferens* (Brown Tide), *Pfiesteria piscicida and P. shumwayae*, *Chattonella*, *Heterosigma akashiwo*, *Fibrocapsa japonica*, *Prorocentrum minimum, Dinophysis sp.*, *Amphidinium sp.*, *Pseudo-nitzchia sp.*, *Karlodinium* and two macroalgae genera (*Gracilaria*, *Chaetomorpha*). Several other HAB species are also present from time to time including cyanobacteria species (*Microcystis*, *Anabaena*, and *Aphanizomenon*), *Gonyaulax*, and *Heterocapsa spp*, Presence of HAB species has been most diverse (i.e. greaterst richness of HAB species) in the polluted tributaries of St. Martin River and Newport Bay (figure 32).

Brown tide is the predominant species that exceeds published threshold levels (see Chapter 6.1). The years 1999 and 2002 had category two blooms in the northern and southern bays, while 2003 had the most extensive bloom (temporally and spatially) in the southern bays when no other area in the northeastern United States reported blooms.

Other threshold exceedances include *Chloromorum toxicum* (formerly *Chatonella cf. verruculosa*) in September 2002 on St. Martin River. A bloom of *C. cf. verruculosa* bloom during 1999 in Delaware Coastal Bays was related to a fish kill event, no evidence of toxicity by any of these species has been associated with similar events in Maryland waters. Threshold exceedances (3,000 cells*ml-1) of *P. minimum* were recorded once each year during April 2001 and 2002 on Bishopville Prong/St. Martin River. *Heterosigma akashiwo* 750-1,000 cells*ml^{-1} have been known to affect mariculture operations, however, *H. akashiwo* has thus far shown no evidence of toxic activity in the coastal bays when recorded above this threshold. *Fibrocapsa japonica* is present in the Coastal Bays but no known cell density thresholds are available to estimate possible effects or warrant intensified surveys for this species.

Dinophysis has been observed above threshold concentrations in Assawoman Bay (2001 once, 2003 once), Isle of Wight (2002 once) and St. Martin Creek (2001 once, 2002 seven times and 2003 twice). However, there is no evidence for toxicity to date in the Coastal Bays systems. All samples could potentially generate intensified monitoring for toxins but > 5 cells*ml^{-1} is

probably a more appropriate threshold. The greatest concentrations of *Dinophysis* (up to 10 cells*ml-1, Canada action threshold is considered 5/ml) were found in areas closed to shellfishing (St. Martin, Turville and Herring Creeks), low concentrations (up to 2 cells*ml^{-1}) were observed in the Isle of Wight

Between 2007-2013, samples from the Maryland Coastal Bays have exceeded suggested living resource effects levels of $\geq$ 10,000 cells*ml-1 for *K. micrum* (2009 and 2011) or 200 cells*ml^{-1} for *Pseudo-nitzschia sp.* Cyanobacteria are encountered but have, in general, declined compared with pre-2000 data; however, pico-cyanobacteria may be increasing. Rare encounters of *Microcystis aeruginosa and other potentially toxic cyanobacteria (Anabaena, Aphanizomenon, Lyngbya, Oscillatoria)* are likely due to limited freshwater and low salinity habitat for this species.

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Table 6.2.3 Potential harmful algae bloom, HAB, species found at each sampling station from 1988 through 2013 in A) above the Ocean City Inet (northern bays) and B) below the Ocean City Inlet (sourthern bays). For a discussion of brown tide (*Aureococcus anafagefferens*) see Ch 6.1.

A. Northern Bays	XDN6454	XDN3445	XDM4486	XDN4797	XDN4312	TUV0011	TUV0019
Aureococcus anafagefferens	√		√	√	√	√	√
Chattonella cf. verruculosa			√	√	√	√	
Chattonella subsalsa			√	√			
Dinophysis sp.		√	√	√	√		√
Fribrocapsa japonica			√	√			
Heterosigma akashiwo			√	√	√		√
Karlodinium sp	√	√	√	√	√	√	
Microcystis sp							
Pfiesteria sp.			√				
Prorocentrum minimum			√	√	√	√	√
Pseudo-nitzschia		√				√	

B. Southern Bays	AYR0017	TRC0043	NPC0012	MSL0011	XDN3724	XBM1301	XDN3527
Brown tide	√	√	√	√	√	√	
Chattonella cf. verruculosa	√	√	√	√			√
Chattonella subsalsa	√	√	√	√			
Dinophysis sp.							
Fribrocapsa japonica							√
Heterosigma akashiwo	√	√	√	√			√
Karlodinium sp	√	√	√	√			√
Microcystis sp	√	√	√				
Pfiesteria sp.							
Prorocentrum minimum	√	√	√	√			
Pseudo-nitzschia							

Chapter 7.1

Maryland Coastal Bays Fisheries Investigations

Steve Doctor

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Abstract
Since 1989, the Maryland Department of Natural Resources has conducted an annual finfish survey at 20 fixed sites in Maryland's Coastal Bays. The Coastal Bays are important finfish nursery grounds. Four species were identified to be representative of the fish assemblages in the Coastal Bays including bay anchovy, black sea bass, silver perch and summer flounder. Bay anchovy and silver perch can be classified as forage species while summer flounder and black sea bass have recreational and commercial importance. This data indicates a favorable habitat with stable population trends.

Introduction
The Maryland Coastal Bays finfish survey was developed to characterize fishes and their abundances in Maryland's Coastal Bays, facilitate management decisions, and protect finfish habitats. The Maryland Department of Natural Resources (DNR) has conducted the Coastal Bays Fisheries Investigations (CBFI) Trawl and Beach Seine Survey in Maryland's Coastal Bays since 1972, sampling with a standardized protocol since 1989. These gears target finfish although bycatch of crustaceans, mollusks, sponges, and macroalgae are common. This report includes data from 1989 – 2013.

Management Objective:
Characterize the stocks and estimate relative abundance of juvenile and adult marine and estuarine species in the Coastal Bays and near-shore Atlantic Ocean.

Methods

<u>Study Area</u>
Maryland's Coastal Bays are comprised of Assawoman Bay, Isle of Wight Bay, Sinepuxent Bay, Newport Bay and Chincoteague Bay. Also included are several important tidal tributaries: St. Martins River, Turville Creek, Herring Creek and Trappe Creek. Covering approximately 363 km^2 (140 mi^2), these bays and associated tributaries average only 0.9 m (3 feet) in depth and are influenced by a watershed of only 453 km^2 (175 mi^2; Maryland Department of Natural

Resources 2005). The bathymetry of the Coastal Bays is characterized by narrow channels, shallow sand bars and a few deep holes.

Trawl sampling was conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October. With the exception of June and September, samples were taken beginning the third week of the month. Sampling began the second week in June and September in order to allow enough time to incorporate beach seine collections.

A standard 4.9 meter (16 ft) semi-balloon trawl net was used in areas with a depth of greater than 1.1 meter (3.5 ft). Each trawl was a standard 6-minute (0.1 hour) tow at a speed of approximately 2.5 knots. Speed was monitored during tows using a global positioning system (GPS). Waypoints marking the sample start (gear fully deployed) and stop (point of gear retrieval) locations were taken using the GPS to determine the area swept (hectares). Time was tracked using a stopwatch which was started at full gear deployment.

Seines were conducted in June and September at 19 fixed sites throughout the Maryland Coastal Bays. A 33 meter (100 ft) bag seine was used in areas with a depth less than 1.1m (3.5ft). The seine was pulled for approximately 33 meter (100 feet). Seine data are not presented in this document.

Data Analysis

Statistical analyses were conducted on species based on their recreational or commercial importance, or biological significance as forage for adult game fish. The Geometric Mean (GM) was calculated to develop species specific annual trawl and beach seine indices of relative abundance (1989-2013). The GM was calculated from the $\log_e(x+1)$ transformation of the catch data and presented with 95% Confidence Intervals (CIs; Ricker 1975). The GM and CIs were calculated as the antilog [$\log_e$-mean(x+1)] and antilog [$\log_e$-mean(x+1) ± standard error * (t value: á=0.05, n-1)], respectively. A geometric grand mean was calculated for the time series (1989-2013) and used as a point estimate for comparison to the annual (2013) estimate of relative abundance

The four species presented here are representative of the fish assemblages of the Maryland Coastal Bays. They are bay anchovy (*Anchoa hepsetus)*, black sea bass (*Centropristis striata),* silver perch *(Bairdiella chrysoura*) and summer flounder (*Paralichthys dentatus).* As with most finfish species found within Maryland's Coastal Bays, most of these species are coastal spawners, illustrating the importance of the Coastal Bays as finfish nursery grounds. Summer flounder and black sea bass are longer lived species of recreational and commercial importance while bay anchovy and silver perch have a shorter life span and serve as a forage base for larger fish.

Results

Bay Anchovy (*Anchoa hepsetus)*
Bay anchovy are often the most abundant species in overall finfish abundance captured by the survey in a year. Both juveniles and adults are captured in the trawl. They are a preferred forage species for larger game fish and have been found occurring with spot and summer flounder at multiple sites in the survey. They are equally abundant in all areas of the Coastal Bays. Being short–lived, they exhibit rather consistent recruitment and abundance. There has been more variance in the abundance in recent years compared to earlier years in the survey. However, the variance has been both above and below the long term mean and not indicative of a trend.

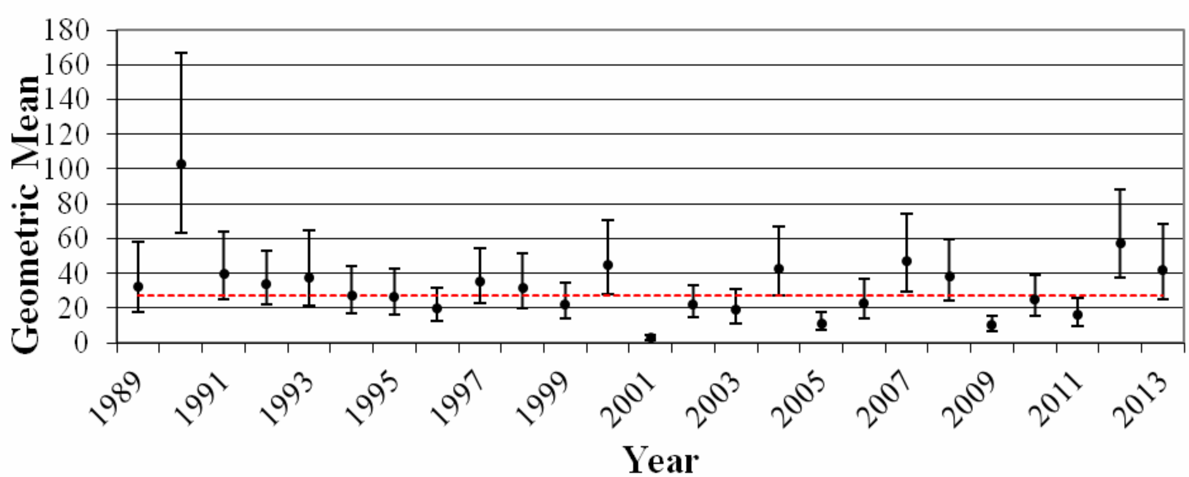

Figure 7.1.1 Bay Anchovy (*Anchoa hepsetus)*trawl index of relative abundance (geometric mean) with 95% confidence intervals (1989-2013). Dotted line represents the 1989-2013 time series grand mean. Protocols of the Coastal Bays Fisheries Investigation Trawl and Seine Survey were standardized in 1989 (n=140/year).

Black Sea Bass (Centropristis striata)
Black sea bass are a species that are important to both recreational and commercial anglers. The survey catches only juveniles so the results are an indication of recruitment variability between years. They are caught in all bays at selected sites by trawl with the most preferred sites in Sinepuxent Bay. Black sea bass prefer structured habitat and are therefore found most often near structure. Sinepuxent Bay offers a lot of structure in the form of rocks, shoreline, and seagrass beds so it is not surprising that they are abundant in this bay. They have a longer lifespan than the forage fish with an effective maximum age of eight years, so as expected, they exhibit more variability in reproductive success than the forage species. From the data, it appears they have three to five year cycles in recruitment.

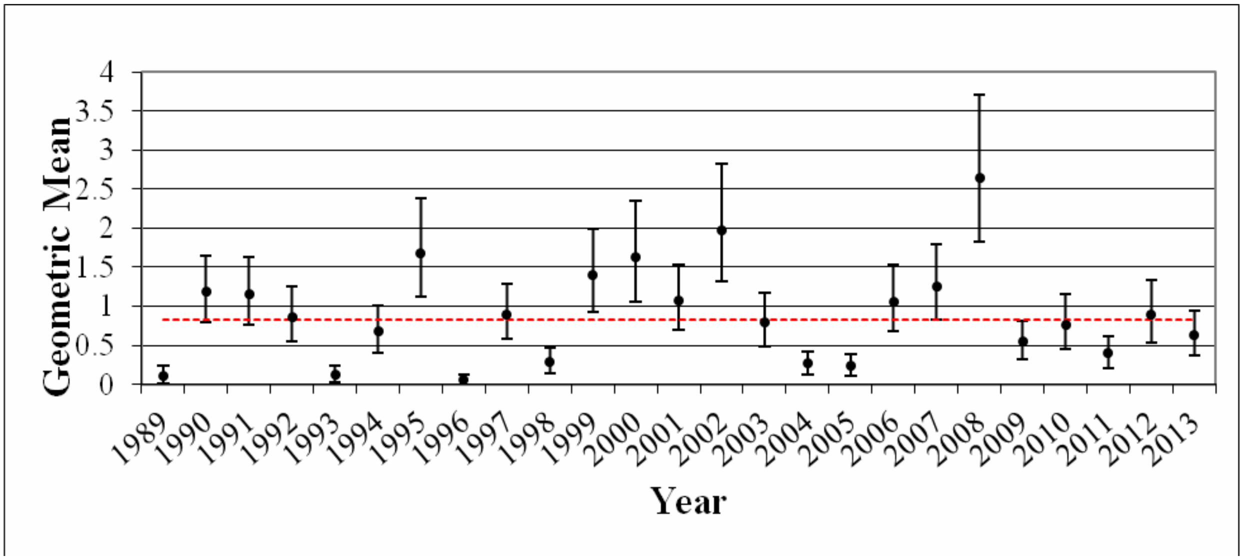

Figure 7.1.2 Black sea bass (*Centropristis striata)* trawl index of relative abundance (geometric mean) with 95% confidence intervals (1989-2013). Dotted line represents the 1989-2013 time series grand mean. Protocols of the Coastal Bays Fisheries Investigation Trawl and Seine Survey were standardized in 1989 (n=140/year).

***Silver Perch (Bairdiella chrysoura*)**

Silver perch usually rank in the top five in abundance in a year. We catch only juveniles in the trawl survey so the index is an indication of yearly recruitment success. Silver perch are widely distributed in the Coastal Bays; however, they prefer sites in Assawoman Bay, St. Martins River, Isle of Wight Bay and Newport Bay, with the highest affinity for the St. Martins River. Silver perch have a maximum age of six years, making them less long lived than game species, but a long lived example of a forage species. Like the bay anchovy, they exhibit relatively stable recruitment from year to year. Recent indices show a little more variability in abundance with some particularly strong year classes.

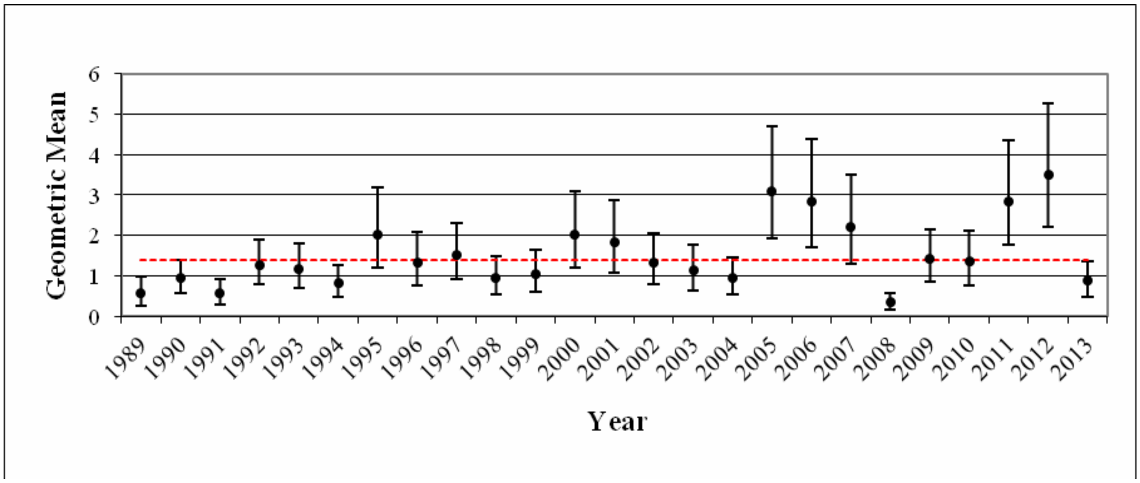

Figure 7.1.3 Silver Perch *(Bairdiella chrysoura*) trawl index of relative abundance (geometric mean) with 95% confidence intervals (1989-2013). Dotted line represents the 1989-2013 time series grand mean. Protocols of the Coastal Bays Fisheries Investigation Trawl and Seine Survey were standardized in 1989 (n=140/year).

Summer Flounder (*Paralichthys dentatus)*

Summer Flounder are probably the most sought after recreational game fish in the Coastal Bays. Almost all the individuals captured by the trawl survey are juveniles, so the index is a reflection of annual recruitment. Summer flounder have preferred sites of abundance in all the Coastal Bays except for Sinepuxent Bay. The more extreme currents found in Sinepuxent Bay may inhibit the preference of juvenile summer flounder for that bay.

Summer flounder have a maximum age of 20 years, so like the black sea bass; they exhibit slightly more variability in recruitment from year to year. However, when compared to other game fish, summer flounder actually have relatively constant recruitment.

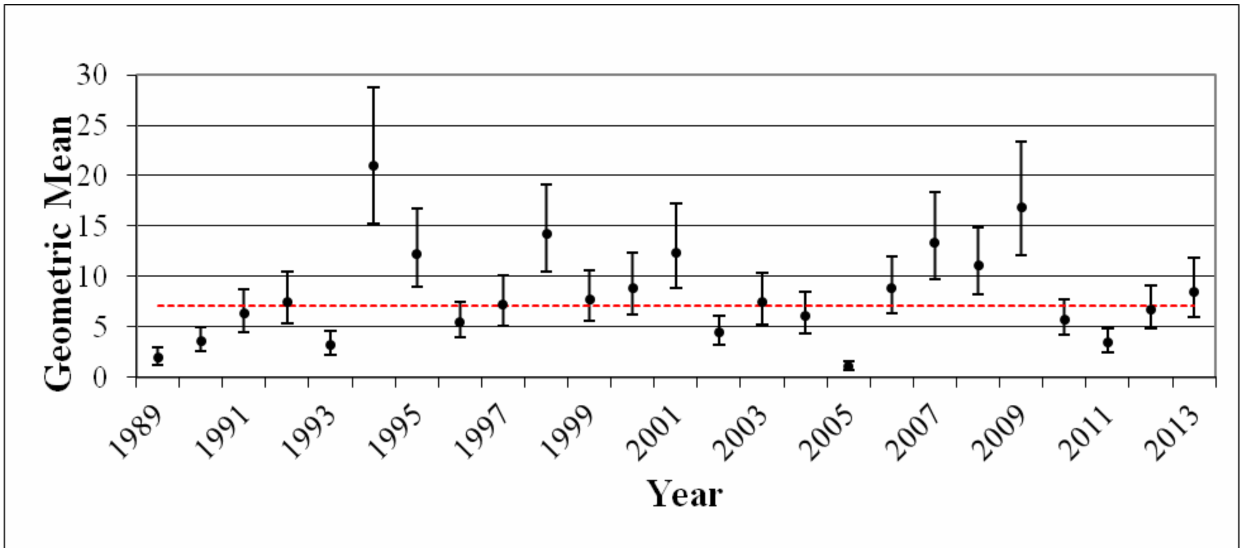

Figure 7.1.4 Summer Flounder (*Paralichthys dentatus)* trawl index of relative abundance (geometric mean) with 95% confidence intervals (1989-2013). Dotted line represents the 1989-2013 time series grand mean. Protocols of the Coastal Bays Fisheries Investigation Trawl and Seine Survey were standardized in 1989 (n=140/year).

Discussion

The four species presented here show different life strategies in annual recruitment dependent on how long they live. The forage species that have shorter life spans have more stable annual abundance while the longer lived game species have more variability in abundance from year to year. Overall the four species presented indicate favorable habitat exists in the Maryland Coastal Bays with stable population trends.

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Chapter 7.2

Fish kill trends in the Maryland Coastal Bays

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Abstract
Fish are analogous to "canaries in coal mines". As such, fish kills are usually indications of unusual stress in the environment. Sporadic fish kills due to low oxygen are apparently increasing in frequency. There have been 77 reported fish kills and 71 confirmed or probable fish kills in the Maryland Coastal Bays since 1984. Collectively they represent approximately 4.5 million mortalities. The majority of fish kills occur in the summer months when there are abundant algal blooms, lower oxygen solubility, increased temperatures, increased oxygen demand from the breakdown of organic matter in the water, and larger fish stocks in the bays. Low dissolved oxygen is implicated in two thirds of all fish kills where the cause is known in the Coastal Bays. The vast majority (97.9%) of mortalities also occurred within dead-end canals.

Introduction
Fishkill investigations are the responsibility of the Maryland Department of the Environment (MDE) under Environmental Article Section 4-405C to investigate the occurrence of damage to aquatic resources, including, but not limited to, mortality of fish and other aquatic life. The investigations should determine the nature and extent of each occurrence and endeavor to establish the cause and sources of the occurrence. If appropriate, findings shall be acted upon to require the reparation of any damage done and the restoration of the water resources affected, to a degree necessary to protect the best interest of the state.

Since 1984 this program has received over 2,300 reports of fish kills and coordinated a statewide, multiagency cooperative response to those reports. Not all reports are investigated for a variety of reasons, including low numbers of dead fish, tardy reporting, or *a priori* information on the source of the dead fish. The Fish Kill Investigation Section maintains a database of all reports, investigation results, and other pertinent details from the last 30 years. This report is a summary of events reported in the Coastal Bays region from 1984-2013 with an emphasis on 2007-2013.

There have been 77 reported fish kills and 71 confirmed or probable fish kills in the Coastal Bays Region since 1984. Collectively they represent approximately 4,535,000 mortalities. During the same period, there were 1,922 fish kill reports, involving approximately 36,255,000 mortalities in the Chesapeake Bay and its tidal tributaries.

Management Objective: Decreasing fish kills that are not 'natural in origin'.

***Draft* Fishkill Indicators**: Number of fishkills due to low D.O. and pollution
Number of dead fish

Status of Fish Kills

Canals are confined spaces with characteristically low flushing where frequent algal blooms can lead to hypoxic or anoxic conditions. Fish often enter dead-end canals because of the deeper and cooler waters found there and become trapped when the conditions become intolerable. Within the Coastal Bays watershed, fish kills were reported in canals more often than in any other type of water body (Figure 7.2.1). Eighteen of the twenty-six reports involving canals were attributed to low dissolved oxygen. The majority (73.5%) of mortalities also occurred within canals (Figure 7.2.2). In addition to fish kills, citizen complaints about nuisance algae in canals were common in the summer time.

Several factors combine to explain reports in canal habitats. Excess nutrient runoff and poor circulation/flushing contribute to algal blooms, diurnal dissolved oxygen sags, and elevated biological oxygen demand (BOD). Additionally, dead end canals may act as traps for wind-blown floating macroalgae. Canals may also act as traps for schooling fish with poor maneuverability in shallow inshore environments. Concentrated fish that have been corralled into canals by predatory fish, or have simply wandered there, can become entrapped by low tides. This often results in the critical depletion of available oxygen due to a combination of fish respiration and natural diurnal oxygen depression.

Another explanation for the number of reports from canals depends on the fact that reports require an observer. With a large population living along canals, the probability of an observer seeing dead fish in a canal is high. There are fewer potential observers for dead fish in more remote areas.

The second most common habitat for fish kill reports is tidal creeks and rivers. Of the 18 reports from creeks and rivers, all but two occurred in smaller creeks near tidal headwaters. The most common cause of these events was low dissolved oxygen (seven of 10 events where cause was determined).

Trends of Fish Kills

<u>Temporal Patterns</u>
The majority of fish kills occur in the summer months in the Coastal Bays as they do throughout the state (Table 7.2.1). Algal blooms, lower oxygen solubility, increased temperatures, increased BOD from organic decomposition and larger fish stocks all occur in summer months. A small increase in the number of kills occurs in the Coastal Bays during the months of January and February. This is largely due to the fact that schools of 5-8" striped mullet (*Mugil cephalus*) have been found dead and dying of cold stress in past winters throughout the area. While most fisheries accounts of the Mid-Atlantic suggest that the species leaves the area in fall and moves south, apparently some attempted to over winter in the area.

Table 7.2.1 Fish kills reported by Month: 1984-2013.

Month	# Reported Kills Statewide	# Reported Kills Coastal Bays
January	74	4
February	88	4
March	133	1
April	273	4
May	580	5
June	631	11
July	577	11
August	463	24
September	325	5
October	90	5
November	38	3
December	26	0

The number of fish kills reported per year varies following trends in ease of reporting, public awareness about fish health and environmental concerns, disease outbreaks, and cyclical trends in weather (i.e. drought, cold winters, cool summers, wet years). The number of kills reported per year is not likely to be changing statewide (Table 7.2.2). However, there is a very recent downward trend in the number of fish kill reports received in the last three years, which may not be significant. In the early to mid 2000's there appeared to be an increase in the number of fish kills reported per year in the Coastal Bays. The average number of kills reported in the late 1980's through the 1990's was 1.5/year. That number has increased to more than six per year from 2000 to 2005. Since then the average is about two, about the same as the 30-year average.

Increased public awareness resulting from renewed interest in environmental initiatives in the Coastal Bays may explain the several year increase in fish kill reports.

Table 7.2.2 Fish Kills per Year: 1984-2013

Year	# Reports Statewide	# Reports Coastal Bays
1984	25	0
1985	90	3
1986	136	0
1987	148	1
1988	187	0
1989	122	1
1990	105	2
1991	120	0
1992	99	2
1993	103	3
1994	84	4
1995	105	2
1996	87	1
1997	87	3
1998	100	0
1999	132	1
2000	178	4
2001	129	5
2002	149	14
2003	126	5
2004	111	3
2005	90	6
2006	90	1
2007	141	2
2008	112	1
2009	98	2
2010	97	3
2011	70	4
2012	97	2
2013	65	2
TOTAL	**3297**	**77**

Cause

Approximately 12% of all fish kills statewide are "pollutional" in nature. Pollution induced fish kills are direct results of discharges of some kind (i.e. sewage spills, manure spills, pesticide misuse, chlorine discharges or chemical spills). Other kills like fishing discards arose directly from anthropogenic factors. "Natural" kills may be entirely natural occurrences such as spawning stress or arise in part from anthropogenic factors such as nutrient runoff.

Statewide, nearly half of all tidal fish kills where the cause was known were attributable to low dissolved oxygen (DO) (Table 7.2.3). These events may have been due to strandings of schooling fish in tidal headwaters, entrapment in commercial fishing nets or other man made structures, low DO that could be attributed to nightly oxygen sags resulting from algal blooms, inversions, or intrusions of deep anoxic water onto shorelines. Low DO was implicated in nearly two thirds of all fish kills where the cause is known in the Coastal Bays. While entrapment in man-made structures accounts for 14% of all low dissolved oxygen kills statewide, it accounts for 35% of all low DO kills in the Coastal Bays.

Table 7.2.3 Fish kills by cause: 1984-2013.

Cause of Fish Kills	**Statewide Cases (% where cause is known)**	**Coastal Bays Cases (% where cause is known)**
Low Dissolved Oxygen	**1003 (43.5 %)**	**35 (63.6%)**
General	335	9
Algal bloom	276	9
Entrapment	137	12
Intrusion/Inversion	91	1
Stranding	61	3
BOD	48	1
Winter Kill	55	0
Unknown	**766 (n/a)**	**16 (n/a)**
Discards	**468 (20.3 %)**	**10 (18.2 %)**
Thermal Stress	**52 (2.3 %)**	**5 (9.1 %)**
Disease	**236 (10.2 %)**	**1 (1.8 %)**
Seasonal/Spawning Stress	**158 (6.9 %)**	**1 (1.8 %)**
Pond Management	**71 (3.1 %)**	**1 (1.8 %)**
Misc. Natural	**16 (0.7 %)**	**0**
Storm Winds	**1 (0.04 %)**	**1 (1.8 %)**
Pollution	**266 (11.5 %)**	**1 (1.8%)**
Toxic Algae	**36 (1.6 %)**	**0**
TOTAL KILLS	**3073**	**71**

<u>Mortalities</u>

Of the estimated 42,128,000 fish mortalities statewide since 1984, 85% died in low DO events. Of the 4,535,460 fish mortalities in the Coastal Bays, approximately 74% died in low oxygen events (Table 7.2.4). Excepting one major event in 2004, the species most affected were schooling species, such as Atlantic silversides (*Menidia menidia*), Atlantic menhaden (*Brevoortia tyrannus*), and striped mullet (Table 7.2.5).

The only pollution case in the Coastal Bays took place on August 7, 1993 in Bishopville Pond. A sudden collapse of a storage tank at a plant in Selbyville, Delaware caused approximately

250,000 gallons of chicken processing waste to spill into the creek feeding Bishopville Pond. Fish mortalities occurred during the night, but were cleaned up by contractors before Maryland Department of the Environment biologists could accurately assess the damage. At least 150 fish died. No acute effects were visible below the pond in Bishopville Prong.

Table 7.2.4 Fish mortalities by cause: 1984-2014.

Cause of Fish Kills	Coastal Bays Mortalities	Statewide Mortalities
Low Dissolved Oxygen	**3,364,552 (74.2%)**	**35,704,570 (84.8 %)**
General	26,422	3,953,960
Algal bloom	25,362	13,732,120
Entrapment	3,200,743	3,572,950
Intrusion/Inversion	10,000	347,640
Stranding	102,000	13,709,250
BOD	25	337,790
Winter Kill	0	50,860
Unknown	**34,388 (0.8 %)**	**731,125 (1.7 %)**
Discards	**131,139 (2.9 %)**	**292,610 (0.7 %)**
Thermal Stress	**1,004,900 (22.2 %)**	**3,089,900 (7.3 %)**
Disease	**0**	**877,910 (2.1 %)**
Seasonal/Spawning Stress	**0**	**32,800 (0.1 %)**
Pond Management	**300**	**81,840 (0.2 %)**
Misc. Natural	**0**	**18,050 (0.0 %)**
Storm Winds	**25**	**25 (0.0 %)**
Pollution	**150**	**1,032,040 (2.5 %)**
Toxic Algae	**0**	**267,450 (0.6 %)**
TOTAL KILLED	**4,535,460**	**42,128,320**

Table 7.2.5 Mortalities of Fish by Species in the Coastal Bays Region: 1984-2014.

Fish species	Number killed in Coastal Bays
Atlantic silversides, *Menidia menidia*	3,000,000
Atlantic croaker, *Micropogonias undulatus*	1,000,045
Atlantic menhaden, *Brevoortia tyrannus*	520,137
Striped mullet, *Mugil cephalus*	5,050
Bluegill sunfish, *Lepomis macrochirus*	2,415
Gizzard shad, *Dorosoma cepedianum*	1,850
Golden shiner, *Notemigonus crysoleucas*	1,375
Minnow species	671
White perch, *Morone americana*	600
Black sea bass, *Centropristis straita*	500

Summary
Two of the top 10 fish kill events occurred during the 2007-2013 timeperiod. The first was a low DO event that occurred in 2010 in a canal off Greys Creek near Bishopville. Approximately 100,000 Atlantic menhaden died. The second occurred in 2011 as a result of commercial fishing discards offshore (Approximately 100,000 adult Atlantic menhaden began washing ashore on Maryland and Delaware beaches). The year 2011 had one of the highest number of reported fish kills (4). Low oxygen is still a major factor in fish kills in the Coastal Bays.

Fish kill events in order of severity were:

1. **August 30, 2001** in a canal off Isle of Wight Bay in West Ocean City. A school of 3,000,000 Atlantic silversides entered the canal, which had a sand bar partially blocking its mouth, and apparently became entrapped during low tide overnight. The fish became concentrated by low water, exhausted all available oxygen, and died. DO at the time of investigation varied between 0.05-2.1 mg/l.
2. **July 31, 2004** in the Atlantic Ocean. At least 1,000,000 Atlantic croaker (a warm water species) died suddenly and began washing ashore in Maryland, Virginia, and Delaware. Investigations by many State, Federal, and University researchers revealed that an event occurred July 31st in the Atlantic Ocean off Ocean City. Researchers showed that a so called "cold pool" of water had been moving southward from off New Jersey and that water temperatures in the Coastal Bays Region dropped prior to onset of the kill. Although the Maryland event was short-lived, croakers reportedly continued to die for several more weeks as migration progressed south along the coast. It is most probable that the initial intrusion of "cold pool" water, timed with mass seasonal migration, initiated both acute and latent stress factors that sustained die-off of the susceptible portion of the population. Independent investigations continued as the kill eventually moved south into Florida waters.
3. **September 22, 1997** in a canal off Assawoman Bay in Ocean City. Approximately 200,000 Atlantic menhaden apparently became entrapped in the canal and died of low oxygen. Dissolved oxgyen at the time of investigation was 0.77 mg/l.
4. **June 4, 2011** in the Atlantic Ocean. Approximately 100,000 adult Atlantic menhaden began washing ashore on Maryland and Delaware beaches. Investigation by various state and federal agencies revealed that the fish apparently were discarded by commercial fishermen offshore near the mouth of Delaware Bay.
5. **October 3, 2010** in a canal off Greys Creek near Bishopville. Approximately 100,000 Atlantic menhaden died. Investigation revealed that wind and tide combined to largely dewater the canal, stranding the fish. A continuous monitor in the canal measured oxygen at lethally low levels.
6. **August 17, 2002** in Massey Branch, a tidal tributary of Marshall Creek. Approximately 30,000 Atlantic menhaden died. Investigation revealed that the creek was extremely shallow and the fish were likely stranded. Most of the dead fish were found in less than eight inches of water. Algal samples revealed a bloom of the potentially toxic alga, *Chattonella sp.* in the area. Other species of fish were unaffected.
7. **July 8, 1993** in the Atlantic Ocean off Assateague Island. Approximately 30,000 adult Atlantic menhaden were discarded by commercial fishing operations.

8. **September 20, 2008** in Bishopville Prong, from Bishopville to the public landing. Approximately 20,000 Atlantic menhaden died throughout the creek due to low DO.
9. **June 7, 2002** in a canal off Isle of Wight Bay in West Ocean City. Approximately 15,000 Atlantic menhaden died due to low oxygen.
10. **September 12, 1985** in a canal off the St. Martin River in Ocean Pines. Approximately 10,000 Atlantic menhaden died due to a storm induced anoxic inversion.
11. **September 4, 2005** in Sinepuxent Bay at Great Egging Island. 700 Atlantic menhaden, Atlantic croaker, and seatrout died due to low dissolved oxgyen.
12. **January 17, 2001** in a canal off Isle of Wight Bay in Ocean Pines. Approximately 3,500 striped mullet died of cold stress under ice.

Acknowledgements
Thanks to the entire field crew who helped collect fish kill related information including crews with DNR (Monitoring and Non-Tidal Assessment Division, Tidewater Ecosystem Assessment Service, Fisheries Service, Natural Resource Police, Paul S. Sarbanes Cooperative Oxford Lab-Fish and Wildlife Health Program) and MDE (Inspection and Compliance Program, Emergency Response, Shellfish Compliance Monitoring Division).

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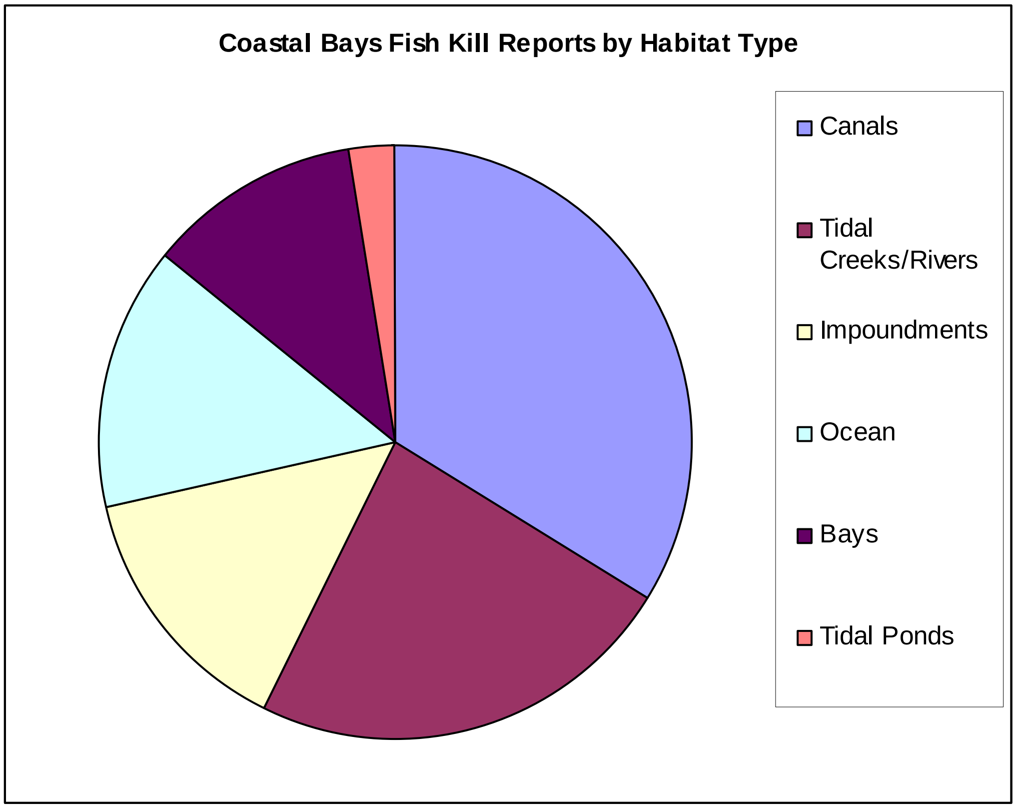

Figure 7.2.1 Number of fish kills per habitat type, 1984-2013.

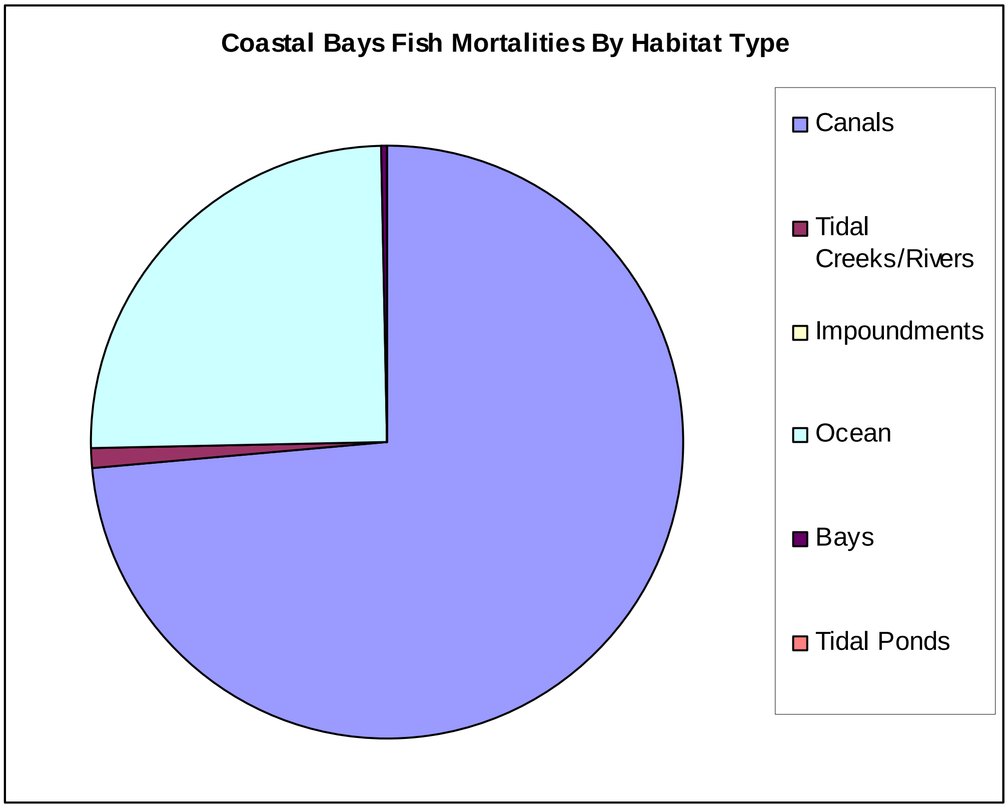

Figure 7.2.2 Numbers of fish killed during fish kill events per habitat type, 1984-2013.

Chapter 7.3
Status of Molluscan Shellfish Populations in Maryland's Coastal Bays

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Abstract
In 1993 the Maryland Department of Natural Resources (DNR) initiated a comprehensive study to inventory the molluscan fauna of the Coastal Bays. Intended to establish baseline values for future management needs, both commercially important shellfish and ecologically valuable species have been targeted. A total of 63 molluscan species, and an additional 10 species represented only by dead specimens, were collected as part of the most recent DNR molluscan survey. Among the findings characterizing the molluscs of the Coastal Bays were the high species diversity and pronounced geographic heterogeneity, the substantial seasonal and annual variability within these assemblages, and the elucidation of their ecological functions and habitats. The intertidal zone was numerically dominated by the ribbed mussel (*Geukensia demissa*) where it is ecologically important in processing nutrients and binding substrate, especially in salt marshes. As for commercial species, none of the 28 documented shell bars in the Coastal Bays have living oysters (*Crassostrea virginica*) and many of the bars are buried under sediment; presently there is only one small oyster population inhabiting a subtidal relic bar in southern Chincoteague Bay. The 2008 ban on mechanical harvesting in the Coastal Bays has had mixed results for the hard clam (*Mercenaria mercenaria*) populations. While hard clam densities have climbed in Isle of Wight Bay and are approaching historical high levels, the Chincoteague population remains at about 25% of estimates made 45 to 60 years ago. Bay scallops (*Argopecten irradians*), which had occurred in most of the Coastal Bays during the early 2000s, have not been observed in Chincoteague since 2005. Some scallops still inhabit the northern bays, albeit in very low numbers. The high degree of spatial and temporal variability due to physical and biological factors within the Coastal Bays creates difficulty in drawing strong conclusions about trends in molluscan population and community dynamics. Consequently, DNR continues to track the population status of select species.

A. Molluscan Community

Mollusc Introduction
The significance of molluscs to the estuarine ecosystem has long been recognized. Over 120 years ago the concept of an ecological community was developed through observations of the faunal assemblages of oyster reefs. Functionally, molluscs serve as a key trophic link between primary producers and higher consumers. Bivalves in particular are important as biogeochemical agents in benthic-pelagic coupling, cycling organic matter from the water column to the bottom. Predatory gastropods contribute to structuring prey assemblages and parasitic snails may serve as disease vectors within host populations. In addition, molluscs can have a pronounced impact on the physical structure of an ecosystem, whether by reworking the sediment, grazing, binding or securing existing substrate, or building new substrate such as oyster reefs. Aside from their ecological roles, many molluscs are commercially valuable, both directly as a harvestable

resource and indirectly as a food source for commercially and recreationally important species including crabs, fish and waterfowl. Some of the potential threats to molluscs in the Coastal Bays include diseases, loss of habitat, invasive species such as green crabs (*Carcinus maenas*) and harmful algal blooms like brown tide (*Aureococcus anophagefferens*).

Molluscan Community Data Sets

Assateague Ecological Studies, 1969-71. Data are as number per m^2 and in tables, sample sites are given on maps.

Maryland Department of Natural Resources surveys, 1980-81. Most samples were from Isle of Wight. Data are in tables (number per unit area) with map of sampling sites.

Coastal Bays Joint Assessment, U.S. Environmental Protection Agency E-MAP Surveys, 1993. Data presented in tables. Sites are depicted on maps. Latitude/longitude sample site information is available from U.S. Environmental Protection Agency.

Mid-Atlantic Integrated Assessment, MAIA, Iteration of E-MAP. Twenty-one sites were sampled between 1997 and 1998. Focus was on Sinepuxent and lower Chincoteague Bays.

National Coastal Assessment, Iteration of E-MAP Surveys, 2000-03.

National Park Service, 1994-96. Box core and trawl samples in Chincoteague and Sinepuxent Bays. Includes seasonal data. Data available from NPS.

Maryland Department of Natural Resources Molluscan Inventory, 1993-96. Population data were collected on individual species (density, distribution, size-frequencies, animal-sediment relationships) and community analyses from Ponar grab, hydraulic dredge, and shoreline quadrat samples. Data are available with geographic and habitat information. This three-year study represents the most comprehensive inventory of molluscan fauna in the coastal bays conducted to date.

Management Objective

Maintain optimum sustainable shellfish abundances.

Molluscan Community Indicators

A. Primary (all species)

1. Species (Genus species)
2. Density (# live/unit area)
3. Geographic Distribution (lat/long; bay or tributary; sub-bay or region)

B. Secondary (species of particular interest)

1. Size-Frequency Distribution (% frequency)

C. Tertiary (species of particular interest)

1. Mortality

a) Natural (boxes/unit area)
b) Harvest (commercial landing records)
2. Disease

Data Collection
Between October 1993 and September 1996, the DNR Shellfish Program carried out a comprehensive effort to inventory the molluscan fauna of Maryland's coastal bays and major tributaries including the St. Martin River and Greys, Turville, and Herring creeks. Intended to establish baseline values for future management needs, both commercially important molluscs and ecologically valuable species were targeted. During the 3-year period approximately 1,800 stations were sampled using five different collection methods including hydraulic escalator dredge, oyster handscrape, Ponar sampler, clam rake and intertidal quadrat. For an account of molluscan sampling, see Tarnowski 1997b.

Molluscan Community Results
Over 50,000 live individuals comprising 63 mollusc species were collected; an additional 10 species were represented by dead specimens only (for a species list, see Appendix A of this volume). Sixteen of these species had not been reported in previously published accounts of the Coastal Bays, including three northward range extensions.

A total of 1,020 Ponar bottom grab samples generated information on population and community parameters such as species composition and hierarchy, distribution, richness, abundance, size structure, and habitat characterization. Among the findings was the highly diverse nature of the coastal bays molluscan communities; the significantly lower molluscan abundances and species richness in the coastal tributaries when compared with the bays; the strong relationships of the species with habitat types including sediment, vegetation, shell cover and other biogenic structures; the elucidation of ecological communities and functions of the coastal bays molluscs; the pronounced geographic heterogeneity of the assemblages; and the distinctive and substantial variability in the molluscan community over time, both on a seasonal and annual basis. Because the Maryland coastal bays are situated at the overlap of two faunal provinces, shifts in community composition may serve as an indicator of climatic change. However, the spatial and temporal variability due to physical and biological factors can confound short-term attempts at detecting disturbances, whether natural or anthropogenic.

In addition to the bottom grab survey, 67 intertidal shoreline quadrat stations and nine intertidal structure stations were sampled. The intertidal zone was numerically dominated by the ribbed mussel (*Geukensia demissa*) where it is ecologically important in processing nutrients and binding substrate, especially in salt marshes. Man-made intertidal structures can provide additional scarce, hard substrate as a supplement, but not substitute, for existing natural intertidal shoreline.

B. Hard Clams

Introduction
The hard clam (*Mercenaria mercenaria*) has long been an important species both in terms of

sustenance and commerce. In addition to being items of food for the indigenous people of the Coastal Bays, the clams were highly valued as a source of purple shell for making wampum beads, the common currency of exchange among tribes all along the Atlantic coast. During recent times, the hard clam was one of the species that flourished in the coastal bays after the Ocean City Inlet opened in 1933. Prior to that time, the population was confined to the higher salinities in southern Chincoteague Bay. Significantly, the improvement of commercial shellfish resources was one of the primary rationales for allocating funds to construct and stabilize a new inlet. Just before construction was to begin, a hurricane serendipitously breached the island at the southern edge of Ocean City, which the Army Corps of Engineers quickly stabilized. New clam populations and an associated fishery consequently developed throughout the bays. Since the 1960s, the hard clam has supplanted the oyster in commercial landings and value in the Coastal Bays, and is the basis of a recreational fishery, especially for tourists that visit the region during the warmer months. However, with the 2008 prohibition of mechanical harvesting for shellfish in the Coastal Bays, the commercial fishery has been practically eliminated.

Hard Clam Data Sets

Maryland Department of Research and Education. 1952-53. System-wide hard clam study includes density, distribution, size structure, and habitat.

University of Maryland Assateague Ecological Studies. 1969-70. Same data classes as above, with emphasis on eastern Chincoteague Bay. No samples above the Ocean City Inlet.

Maryland Department of Chesapeake Bay Affairs; Maryland Department of Natural Resources. 1968-71. Surveys of commercial hard clam areas.

Maryland Conservation Department; Bureau of Natural Resources; Dept. Chesapeake Bay Affairs. 1928-1969. Annual Reports. Annual landings and licensing data as well as occasional anecdotal information.

Maryland Department of Natural Resources Shellfish Program. 1993-present. System-wide hard clam surveys includes density, distribution, size structure, habitat and other organisms. Bay scallops and other select species are included in this survey, in addition to limited surveys dedicated to scallops.

Management Objectives

Maintain optimum sustainable clam abundances.

Hard Clam Indicators

1. Density (# live/unit area)
2. Geographic Distribution (lat/long; bay or tributary; sub-bay or region)
3. Length-Frequency Distribution (% frequency)
    a) Recruitment (% sublegal clams 31-50 mm shell length)
    b) Average length
4. Mortality
    a) Natural (% dead)

b) Fishing (commercial landings records)
5. Disease

Data Collection
Since 1993, the Maryland Department of Natural Resources Shellfish Program has conducted annual surveys of the hard clam population in Chincoteague Bay. These surveys were expanded in 1994 to include the remainder of the Coastal Bays. A commercial hydraulic escalator dredge is towed along a 76.2 m transect at each site, effectively sampling 58.1 m^2 of bottom. The number of stations has increased over the years; since 2012 a minimum of 260 randomly-selected samples have been taken. Sampling is stratified by embayment, with Chincoteague Bay being further quartered. In addition, since 2012 Sinepuxent Bay has been stratified into two (upper and lower) sections. A size bias is associated with this gear; it does not adequately sample clams smaller than 31 mm shell length. For more details about hard clam data collection and analysis, see Homer (1997).

Hard Clam Results: Status and Trends

Table 7.3.1 Summary of Maryland Department of Natural Resources Hard Clam Surveys (2007-2013) and 1953 clam densities.

	Seven-Year Averages (2007-2013)					1953
	Total n	Length (mm)	%< 51 mm	% Dead	Live/m^2	Live/m^2
Chincoteague Bay	957	79.1	7.8	3.4	0.18	1.30
Newport Bay	70	80.1	4.6	4.8	0.10	0.40
Sinepuxent Bay	203	79.1	14.0	2.6	0.33	1.04
Isle of Wight Bay	206	70.6	22.5	1.2	0.73	1.19
Assawoman Bay	159	67.9	24.1	1.8	0.28	1.00
St. Martin River[1]	20	76.9	17.0	1.4	0.06	0.14

[1] Surveys in 2008 and 2011.

1. Chincoteague Bay
a) 2013 Status

A total of 140 samples were taken employing a commercial clamming vessel equipped with a hydraulic escalator dredge (Fig. 7.3.1). Average density was 0.24 clams/m^2, ranking Chincoteague Bay fourth among the five bays. Clams were more abundant on the east side of the bay, with highest concentrations in the southeast quadrant (0.32 clams/m^2). The lowest density was in the northwestern quadrant (0.18 clams/m^2). Observed mortality was low - the proportion of boxes in the population was only 2.7%. The average length of the clams was 78.6 mm, with only 6.6% in the 31 - 50 mm size class, indicating relatively low recruitment.

b) 7-Year Trend

Between 2007 and 2013, a total of 957 stations were sampled in Chincoteague Bay, averaging 0.18 clams/m^2 (Table 7.3.1). Despite the 2008 ban on mechanical harvesting, hard clam population densities continued to decline, reaching their lowest point on record in 2010 when densities averaged only 0.12 clams/m^2, or less than 10% of the historical benchmark (Fig. 7.3.2). Thereafter densities climbed back to about the 20-year average of 0.23 clams/m^2. Clam densities were higher on the east side of the bay during this period. Boxes comprised only 3.4% of the population. Recruitment was poor, as reflected by the 2007-13 average clam length of 80.1 mm, with only 7.0% in the 31 - 50 mm size class. In comparison, the 20-year average proportion of these small clams was 10.2%; during the 7-year trend period only 2010 (13.8%) exceeded this (Fig. 7.3.3).

c) 60-Year Benchmark

Four surveys were conducted intermittently over a 17-year interval prior to the most recent DNR effort, but only the 1953 survey included the entire coastal system. Three of the studies were during the 1950s, when the most of the population had been established for only about 20 years. These initial densities were low relative to other regions along the Atlantic coast and steadily declined during this period, from 1.34 clams/m^2 in 1952 to 1.09 clams/m^2 in 1969. Nevertheless, in 1953 Chincoteague Bay had the highest clam densities of the Maryland coastal bays and was ten times higher than the present 7-year average (Table 7.31, Fig. 7.3.2). Mortality data is not available for these surveys. The average length was little different from the present, ranging between 82.5 mm (1952) and 71.9 mm (1969). Recruitment seems to have always been low, with the proportion of clams between 31 mm and 50 mm in length varying from 2.2% in 1952, to 7.6% in 1958, to 14.4% in 1969.

2. Newport Bay

a) 2013 Status

Hard clam densities averaged 0.15 clams/m^2 over 10 stations, the lowest density of the coastal bays (Fig. 7.3.1and 7.3.2). Boxes comprised 1.1% of the Newport Bay population. The average length of these clams was 82.1 mm, with a mere 1.4% of the clams between 31 mm and 50 mm (Fig 7.3.3).

b) 7-Year Trend

Since 2007, a total of 70 samples have been taken in Newport Bay (Table 7.3.1). Clam densities consistently have been the lowest of the five primary coastal bays, averaging 0.10 clams/m^2 (Fig. 7.3.2). Observed mortalities dropped substantially over this period - box counts averaged 4.8% of the population, compared with the 19-yr average of 13.6%. Recruitment was consistently poor, averaging 4.6% of the sampled population between 31 mm and 50 mm in length; two of the years had no sublegal-size clams (Fig. 7.3.3). This is further indicated by the high proportion of larger, older clams, with a 7-year average length of 80.1 mm.

c) 60-Year Benchmark

Newport Bay has always ranked lowest in clam densities among the Maryland Coastal Bays. Between 1952 and 1969, densities dropped from 0.51 clams/m^2 to 0.08 clams/m^2, which is lower than the present population (Fig. 7.3.2). Historic recruitment data are not available.

3. Sinepuxent Bay

a) 2013 Status

The average live clam density of 0.48 clams/m^2 was the highest recorded in Sinepuxent Bay over the 19-year time series, and was the second highest among the Maryland coastal bays this year (Fig. 7.3.2). This was still slightly less than half of the 1953 baseline data. A total of 40 samples were collected, evenly divided between the upper and lower bay (using the Verrazzano Bridge as the demarcation line) (Fig. 7.3.1). Boxes accounted for 1.1% of the population. The average length was 78.2 mm, with 12.4% of the sampled population between 31 mm and 50 mm (Fig. 7.3.3).

b) 7-Year Trend

Sinepuxent Bay live clam densities have been relatively stable since 2007, averaging 0.33 clams/m^2 with 203 samples taken in total (Table 7.3.1). This is almost identical to the 19-year average of 0.32 clams/m^2. More recently, however, the trend has been upward; the peak density of 0.48 clams/m^2 in 2013 was the highest recorded for this bay during the 1994-2013 period (Fig. 7.3.2). The 7-year average observed natural mortality was 2.6%. This is one of the more consistent areas of recruitment; averaged over the past seven years, 14.0% of the clams were less than 51 mm, which is slightly under the 19-year average of 15.9%. Peak recruitment was 34.7% in 2009, after when the proportion of small clams fell below the time series average (Fig. 7.3.3). Despite this influx of small clams into the population, in the absence of harvesting, the average size of individual clams continued to grow, averaging 79.1 mm in length for the last 7-year period. The 19-year average was 75.2 mm shell length.

c) 60-Year Benchmark

Surveys in 1953 and 1969 yielded similar densities of about 1 clam/m^2 (Fig. 7.3.2). Recruitment data from the 1950s comparable to the present surveys are not available, although this bay was considered to have the most consistent recruitment. Recruitment in 1969 was lower than the present trend, with 11.1% of the population between 31 mm and 50 mm in length.

4. Isle of Wight Bay

a) 2013 Status

This bay had the highest clam density of the Maryland coastal ecosystem, averaging 0.95 clams/m^2 from 40 samples (Figs. 7.3.1 and 7.3.2). This density is 80% of the historical baseline, the highest percentage in the Coastal Bays. The observed natural mortality was 1.0%. The average length was 80.7 mm, with 7.5% of the population between 31 mm and 50 mm (Fig. 3).

b) 7-Year Trend

Isle of Wight Bay appears to have benefitted the greatest from the 2008 dredging ban in conjunction with favorable recruitment from 2005 through 2009. This bay ranked first among the Coastal Bays in clam densities during the past seven years, averaging 0.73 clams/m^2 from 206 samples (Table 7.3.1). Since 2011, the density has been even higher, averaging 0.99 clams/m^2 - more than double the 19-year average of 0.47 clams/m^2 and approaching the historical benchmark - but it also appears that densities have leveled off during this period (Fig. 7.3.2). Observed natural mortality was the lowest of the coastal bays, with boxes accounting for 1.2% of the population. This bay has enjoyed good recruitment over the past few years, with the proportion of clams smaller than 51 mm averaging 22.5% over the 7-year period (identical to the 19-year average) and peaking at

48.5% in 2009 (Fig. 7.3.3). However, over the past three years recruitment has dropped off considerably, averaging only 8.8%. The high recruitment rate is reflected in the lower average length of the sampled population, 70.6 mm.

c) 60-Year Benchmark

Prior to 1994, the only hard clam survey in this bay was conducted in 1953. The average clam density was 1.19 clams/m^2, which ranked it second among the Coastal Bays (Fig. 7.3.2). Historical recruitment data comparable to the present surveys are not available.

5. Assawoman Bay

a) 2013 Status

A total of 30 stations yielded an average density of 0.37 live clams/m^2 (Figs. 7.3.1 and 7.3.2) and an observed natural mortality of 1.5%. The average length of the sampled population was 74.7 mm, with 13.1% of the clams between 31 mm and 50 mm (Fig. 7.3.3).

b) 7-Year Trend

Clam densities, which had been low relative to most of the other coastal bays, have increased since the 2008 prohibition on mechanical harvesting. The 7-year average of 0.28 clams/m^2, based on 159 samples (Table 7.3.1), was almost double the average of 0.15 clams/m^2 for the preceding 11 years, placing it slightly higher than Chincoteague Bay. This upward trend seems to be continuing, with the last two years averaging 0.35 clams/m^2 (Fig. 7.3.2). The observed mortality has also been consistently low, averaging 1.8%. Recruitment was poor during the mid-2000s but jumped in 2007, with an average of 24.1% between 2007 and 2013 (Fig.4). Like Isle of Wight Bay, the peak year was 2009, when 43.1 % of the clams were under 51 mm, the highest in the 19-year time series (Fig. 7.3.3). This trend is reflected in a lowering of the average lengths, bottoming out at 62.0 mm in 2009 and resulting in a 7-year average of 67.9 mm. Since then recruitment has dropped off with the last three years averaging 15.8%.

c) 60-Year Benchmark

Prior to 1994, the only hard clam survey in this bay was conducted in 1953. The average clam density was 1.0 clam/m^2 (Fig. 7.3.2). Historical recruitment data comparable to the present surveys are not available.

6. St. Martin River

a) Recent Status

Over the recent 7-year period, this coastal tributary was surveyed in 2008 and 2011, when a total of 20 samples were taken (Table 7.3.1). For the two survey years, clams were observed at only 55% of the stations, whereas in the bays they are found at almost 100% of the stations. Clam densities were the lowest of any coastal bay region, averaging 0.06 clams/m^2 (Fig. 7.3.2). Observed mortalities were low, averaging 1.4% for the two years. In 2008, one uncharacteristically sandy station provided all but one of the sublegal–size clams found in this river, resulting in an inflated recruitment of 28.6% (Fig.7.3. 3). If this station is ignored, recruitment was 7.7% (one sublegal of 13 clams total). A more typical scenario was in 2011, when clam lengths were the largest of the Coastal Bays, averaging 82.8 mm, with 5.4% of the clams between 31 mm and 50 mm. Aside from the one sandy station, the bottom at the remainder of the locations in the 2008 survey was often soupy mud, with clams absent in 50% of the stations. The high proportion of small clams at the station with sand substrate and their absence elsewhere suggests that the recruitment potential in the St. Martin River is constrained by generally unsuitable habitat. Due to pollution, this river has been closed to shellfish harvesting for many years, yet the clam population remains sparse.

b) 60-Year Benchmark

This tributary seems to be inhospitable to hard clams. The 1953 survey averaged 0.14 clams/m^2, well below the contemporaneous densities observed in the bays, although this figure was based on only three stations (Fig.7.3. 2). Historical recruitment data comparable to the present surveys are not available.

Hard Clam Summary

Despite a ban on mechanical harvesting for shellfish in the Coastal Bays that went into effect in 2008, current hard clam densities in all of the bays remain lower than historical levels. However, density trends in the northern bays have been improving, with the Isle of Wight Bay clam population approaching the 60-year benchmark. Although closed to shellfish harvesting for decades, the St. Martin River continues to have the lowest clam densities in the Coastal Bays. Observed mortalities have been negligible throughout the bays. The Coastal Bays populations are dominated by older, larger clams, with recruitment generally low and sporadic in the lower bays. Parts of Sinepuxent, Isle of Wight and Assawoman bays experienced a strong recruitment period during the late 2000s which accounted for the boost in clam densities, but has tailed off since then.

C. Oysters

The variety of the eastern oyster (*Crassostrea virginica*) known as Chincoteagues has long been prized for its salty flavor, providing profitable livelihoods to generations of watermen in the remote villages along the shores of the bay for which they were named. Immediately following the Civil War, the unique conditions of the region led to the culturing of oysters, an advanced practice at the time that no doubt sustained the industry much longer than it otherwise would have lasted. In addition to their commercial value, oysters are ecologically important as reef builders, contributing structure and hard substrate to a rich community of organisms associated with them in an otherwise soft-bottom environment. The shell provides protection from predation in areas that are otherwise devoid of shelter, benefitting the newly settled juveniles and small adults of numerous species, including hard clams. As filter-feeders, oysters are important in processing organic matter and nutrients from the water column. However, episodic natural events, in particular the opening and stabilization of the Ocean City Inlet, fundamentally changed the coastal bays ecosystem, creating a situation where oyster populations and the industry they supported, could no longer exist. Equally important, the demise of the Coastal Bays oyster has resulted in the loss of a critical functional component of the ecosystem and the gradual disappearance of a significant structural element as well.

Oyster Data Sets

Yates oyster bars survey of 1907.

Maryland Conservation Bureau; Maryland Conservation Department; Md. Bureau of Natural Resources; Maryland Department of Chesapeake Bay Affairs. 1916-1969. Annual Reports. Annual landings and licensing data as well as occasional anecdotal information.

Maryland Department of Natural Resources oyster bars survey of 1994. Revisits the old Yates bars. Data include surface shell per 1.5 minute dredge tow and associated species. No oysters were found.

Maryland Department of Natural Resources. 1994-95. Intertidal survey of Chincoteague Bay. Data include molluscan species, abundance (live and dead), and sizes per 0.25 m^2 quadrat.

Maryland Department of Natural Resources. 1994-95. Oyster survivorship study in Chincoteague Bay. Data include survivorship, growth, disease, and predation from arrays of suspended bags containing hatchery reared oysters.

Maryland Department of Natural Resources. 1999-2007. Dynamics of an intertidal oyster population in West Ocean City. Annual data include density of live and dead, recent or old boxes, height-frequency distributions, spat settlement, presence of drill holes, number of drills, presence of other species, and disease analyses.

Maryland Department of Natural Resources. 2005-present. Subtidal oyster population in Chincoteague Bay. Annual data include recruitment, height-frequency distributions, mortality estimates, and disease analyses.

Management Objectives

None

Oyster Indicators

1. Density (# live/unit area when feasible)
2. Geographic Distribution (lat/long; bay or tributary; sub-bay or region)
3. Height-Frequency Distribution (% frequency)
4. Mortality (% dead)
5. Disease

Data Collection

In 1994, all 28 formerly charted oyster bars were sampled by handscrape along a total of 150 transects throughout Chincoteague Bay. For details, see Tarnowski 1997c. A 0.25 m^2 quadrat was used to annually sample an intertidal population at West Ocean City from 1999-2007. Since 2005, a subtidal oyster population in southern Chincoteague Bay has been sampled annually using a commercial clamming vessel equipped with a hydraulic escalator dredge.

Oyster Results: Status and Trends

1. Recent Status

None of the 28 documented shell bars in the Coastal Bays have living oysters.
In addition to the 150 handscrape tows taken in 1994 on the former oyster bars of

Chincoteague Bay, almost 4,000 clam dredge stations throughout the coastal system have been sampled over the past twenty years and never has a live oyster been found on the old oyster grounds. To a large extent the bars themselves have been buried by sediment, greatly reducing this ecologically important habitat.

First observed in 2005, presently there is only one small oyster population inhabiting an uncharted subtidal bar in southern Chincoteague Bay. The 2013 survey found the population dominated by larger, older oysters, with an average shell height of 98.4 mm (Fig. 7.3.4a). Over the 10-year time series there were recruitment peaks in 2008 and 2010, but since then spatfall has dropped off (Fig. 7.3.4b). Only two spat (3.2% of the total) and one additional sublegal oyster were observed during the latest survey. Recent disease levels have been low, both for *Perkinsus marinus* and *Haplosporidium* spp. infections (Fig. 7.3.4c). Despite these low disease levels, mortalities have increased in recent years, averaging 10.2% from 2005 to 2008 and 23.9% from 2009-2012 (Fig. 7.3.4d). The shells of the individuals were heavily riddled with boring sponge (*Cliona* sp.), and the average meat condition was a relatively poor 3.8 on a scale where 1 = watery and 9 = fat. Given the large percentage of older oysters in poor condition, the low recruitment exacerbated by heavy biofouling competing for settlement space, and the increasing mortalities, it appears this population might be dying out.

Small, relic oyster populations still exist intertidally at a few locations throughout the coastal bays, with occasional spatfall on man-made structures such as riprap, pilings, and bridge supports. From 1999 to 2007, DNR Shellfish Program monitored one such population in West Ocean City, a single year class that set in 1998(Fig. 6). Over the course of the study period, the population density declined to less than 1% of the initial survey findings, from 480 oysters/m^2 to 4 oysters/m^2. Despite the long-term absence of significant oyster populations in the Coastal Bays, at least two major oyster diseases, dermo (*Perkinsus marinus*) and SSO (*Haplosporidium costalis*), were still detected. While earlier mortalities could be attributed in large part to predation, as evidenced by drill holes in the shells of dead oysters, subsequent mortalities were more likely due to an increase in dermo disease levels.

2. Historical Trends

The Yates Survey of 1907 identified 1,665 acres of oyster bars in the coastal bays, all confined to Chincoteague Bay. No bars existed in the upper bays as the water was not salty enough to support oysters. Even in the northern portion of Chincoteague Bay, oysters were subjected to occasional killing freshets, and poor growth and sporadic spatfalls were the norm. With the opening of the Ocean City Inlet in 1933 and its subsequent stabilization came the expectation that oysters would flourish with the increased salinities, creating a scramble to obtain leases for oyster growing bottom. This optimism was short lived, however, as a host of problems associated with increased salinities ultimately proved ruinous to the oyster industry. The elevated salinities allowed predators, particularly oyster drills, to thrive. Fouling organisms that compete for food and hard substrate also found conditions more suitable. Although the natural oyster populations rapidly declined, the culture based industry still managed to exist for some time longer. The death knell of the oyster industry sounded when disease came to the coastal bays in the late 1950s. The last recorded landings were in 1983.

Oyster Summary
The demise of the Coastal Bays oyster has resulted in the loss of a critical functional component of the ecosystem and the gradual disappearance of a significant structural element as well.

D. Bay Scallops

Among the more exotic of the Coastal Bays bivalves is the bay scallop (*Argopecten irradians*). Unlike other species, which are bound to some substrate either by burrowing or attachment, adult bay scallops are free-living and extremely motile, even though they lack a characteristic foot that most active bivalves possess. They are capable swimmers for short distances, which they accomplish by jetting water through their valves, generally in response to predators. Other unusual scallop attributes are their 18 pairs of blue eyes and hermaphroditic reproductive strategy, concurrently possessing both male and female sex organs. Bay scallops have relatively short life spans of only about 12 to 24 months, compared to the 40 year maximum life span of the hard clam. Their preferred habitat is eelgrass beds (providing the beds are not too thick), although they can also be found on other firm substrates such as shell and hard sand. Traditionally, scallops have been appreciated both for the succulent flavor of their adductor muscle and the aesthetic value of their shells.

Bay Scallop Data Sets

Maryland Department of Natural Resources. 1995-2001. Re-establishment of the bay scallop in Chincoteague Bay. Data from predator exclosures include abundance, survivorship, size distribution, growth, predation rates, and gametogenesis.

Data sets for scallops in the wild are identical to those used for hard clams.

Management Objective

Re-establish bay scallop populations in the bay.

Bay Scallop Indicators

1. Density (# live/unit area)
2. Geographic Distribution (lat/long; bay or tributary; sub-bay or region)
3. Size-Frequency Distribution (% frequency)

Bay Scallop Results: Status and Trends

1. Current Status

This species' status remains tenuous in the Coastal Bays. During the 2013 survey, only two bay scallops were caught out of 260 stations, both in eelgrass beds in Sinepuxent Bay. Eelgrass beds, the preferred habitat of bay scallops, appear to have diminished throughout the bays. A transect run in Assawoman Bay just north of the Rt. 90 bridge found that a formerly lush grass bed was reduced to a few sprigs of eelgrass, and was largely supplanted by macroalgae. No scallops have been observed in Chincoteague Bay since 2005.

2. Historical Trends

Evidence of former bay scallop populations in the coastal bays includes ancient shells dredged up during the hard clam surveys or scattered on the beaches of Assateague Island. During the 1920s bay scallops were the object of a modest but lucrative fishery based in Chincoteague, Virginia. Generally, however, salinities in the Maryland coastal bays during this period were too low to support scallops. Although the opening of the Ocean City Inlet in 1933 raised salinities to suitable levels, bay scallops were unable to exploit the new areas available to them because the eelgrass beds had been largely eliminated by "wasting disease" during the early 1930s. Scallops made a brief return to the Coastal Bays during the late 1960s but soon disappeared.

In an attempt to re-establish a population in Chincoteague Bay, DNR Shellfish Program planted 1.2 million bay scallops and raised them to reproductive age during 1997 and 1998. At the same time, wild scallops of unknown origin appeared in the vicinity of the Virginia state line. Mimicking the pattern of seagrass expansion a decade earlier, the geographic spread of the scallop population occurred relatively rapidly in a northerly direction. By 2002, for the first time, live scallops were recorded north of the Ocean City Inlet, both in Isle of Wight and Assawoman bays. Considering the inadequate habitat conditions for this species that had existed in the upper bays until recently (low salinity prior to 1933, absence of eelgrass beds afterwards), these scallops were possibly the first to occur in this area in well over a century. Their widest distribution was in 2002, when bay scallops were caught at 8% of the Shellfish Survey stations throughout the Coastal Bays (except Newport Bay, which lacked suitable habitat) from the Virginia to the Delaware state lines, albeit in very low numbers. This represents the greatest geographic extent of the species in Maryland. Thereafter, their range began to contract, to the point that since 2005 no scallops have been found in Chincoteague Bay, which ironically has the greatest amount of eelgrass habitat and the least development of the Coastal Bays, and was the first bay with an established scallop population. After a brief resurgence in the northern bays in 2008-09 (Fig. 5), the scallop population density receded just as quickly, coincident with a loss of eelgrass in Assawoman and Isle of Wight bays. From 2010 to the present, scallops were caught in less than 1% of the survey stations, with none found in 2011.

Bay Scallop Summary

Extremely low densities over the past four years, diminishing habitat, and declining water quality suggest that the long-term viability of the bay scallop population is in question.

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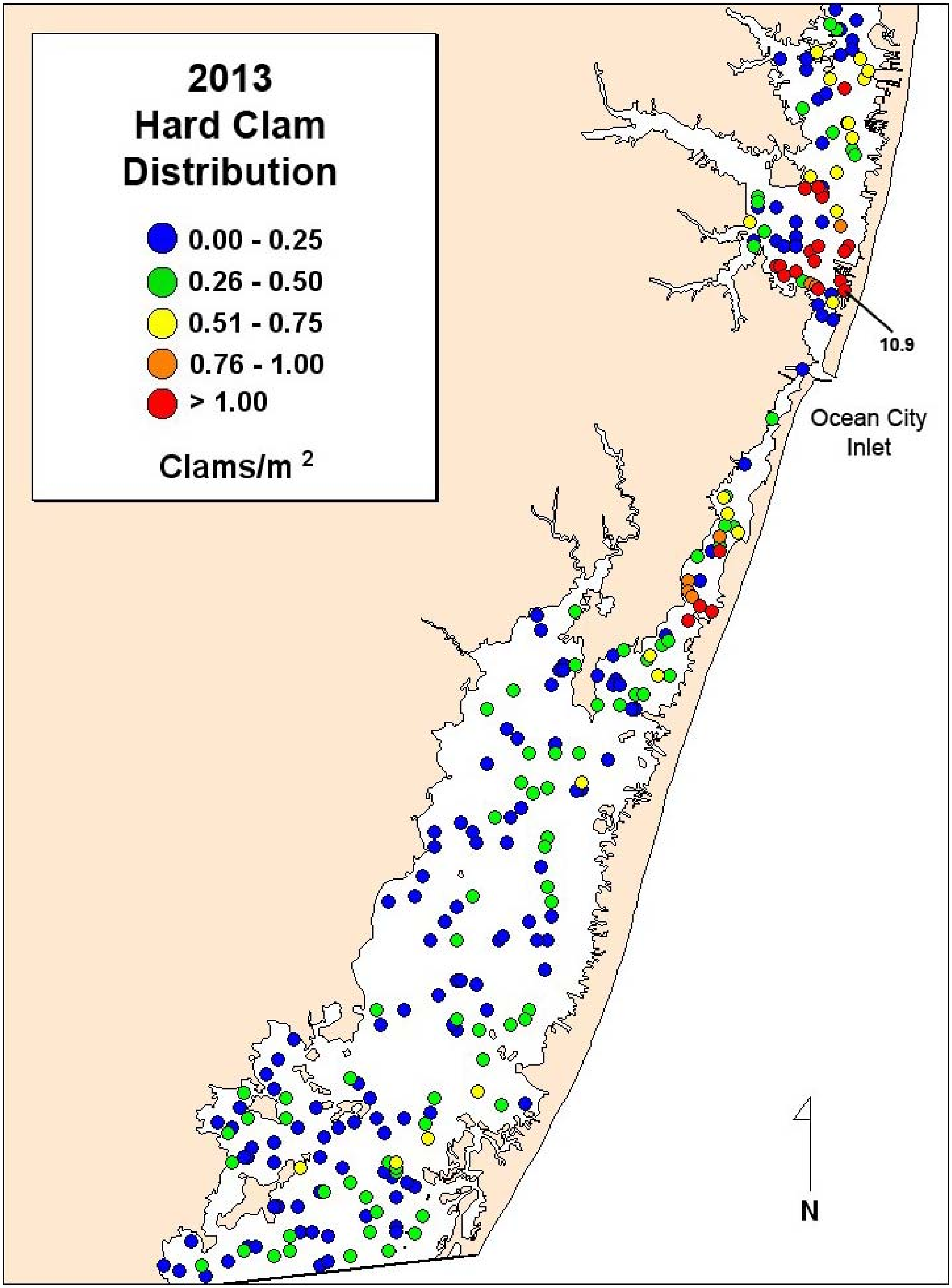

Figure 7.3.1 Hard clam station locations and densities from the 2013 survey. Clam density is measured in number of live clams/m^2.

Hard Clam Densities

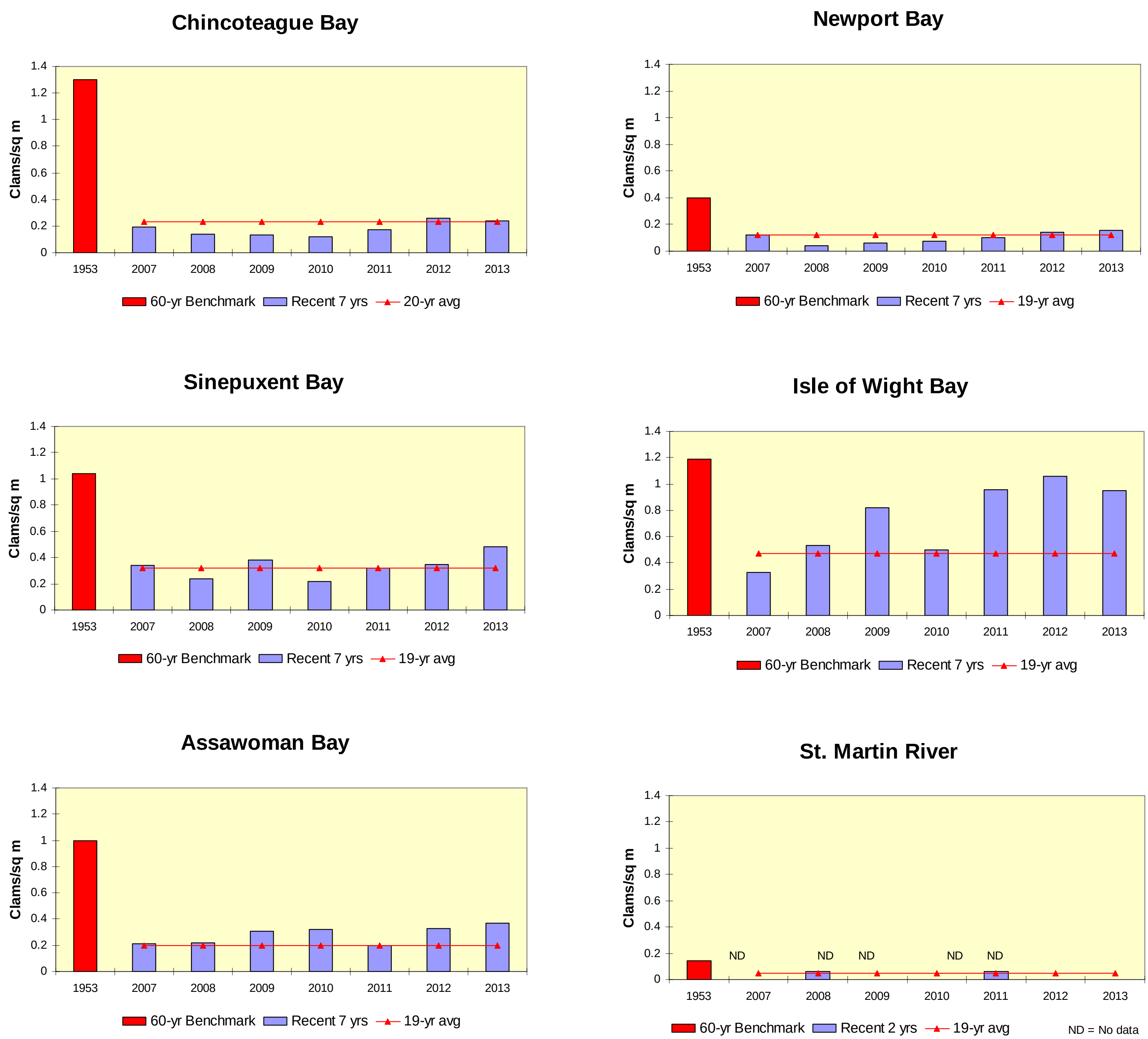

Figure 7.3.2 Hard clam densities per Coastal Bays segment, 2007-2013 and 1953 benchmark. Only Chincoteague Bay was surveyed in 1993.

Hard Clam Recruitment

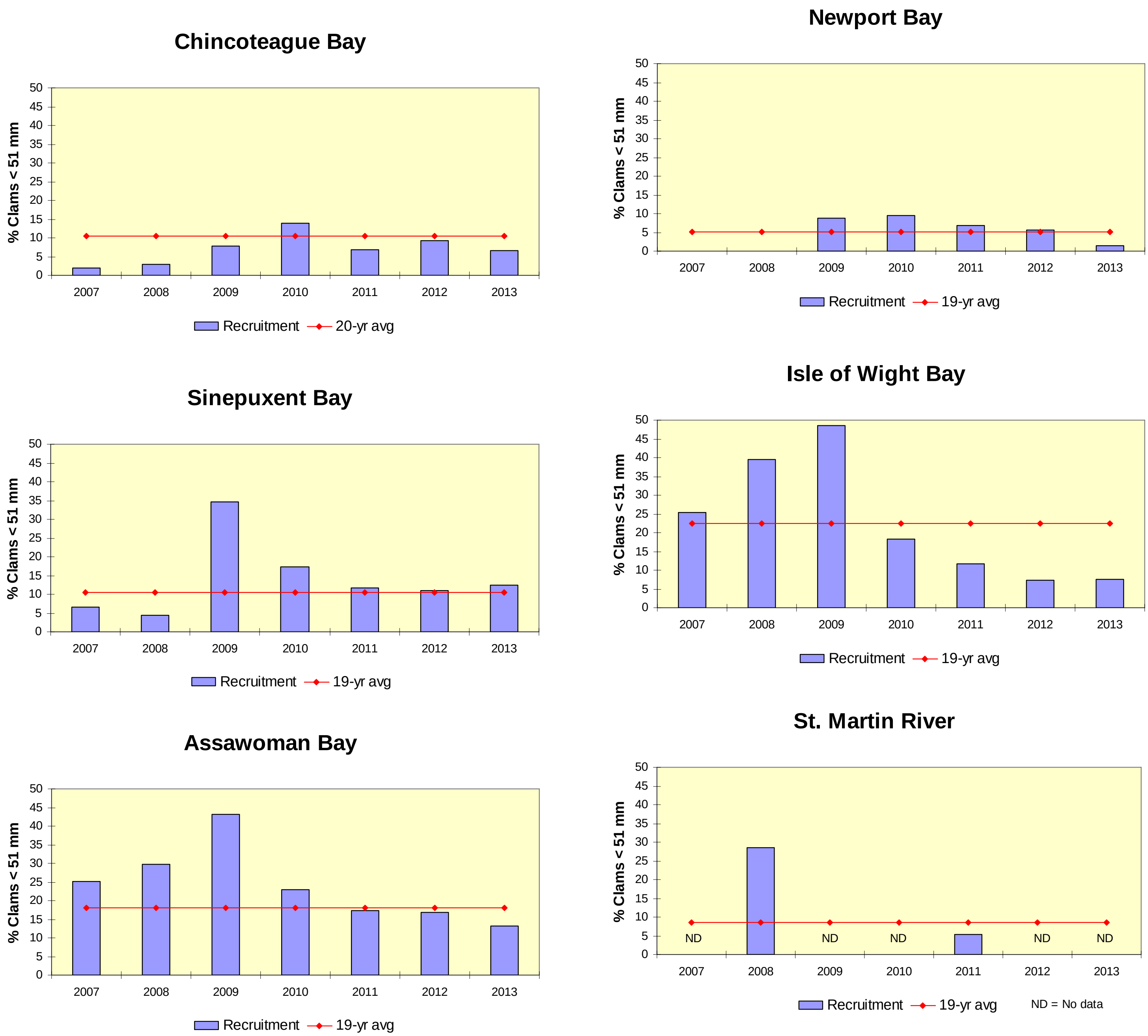

Figure 7.3.3 Hard clam recruitment per Coastal Bays segment, 2007-2013. Only Chincoteague Bay was surveyed in 1993.

Chincoteague Bay Subtidal Oyster Population

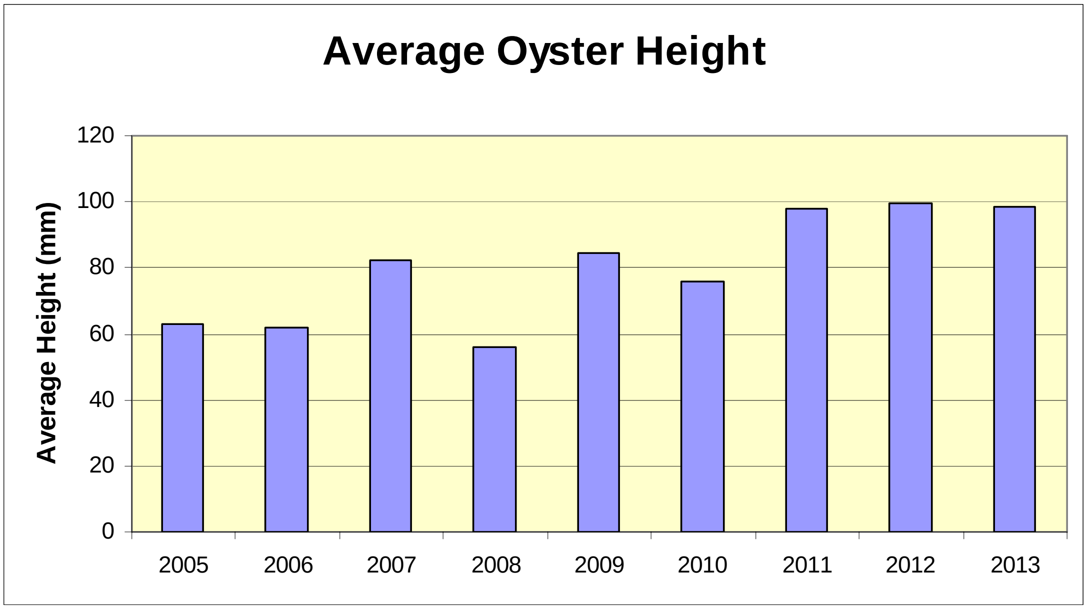

Figure 7.3.4a. Average size of oysters in the Chincoteague Bay subtidal population, 2005-2013.

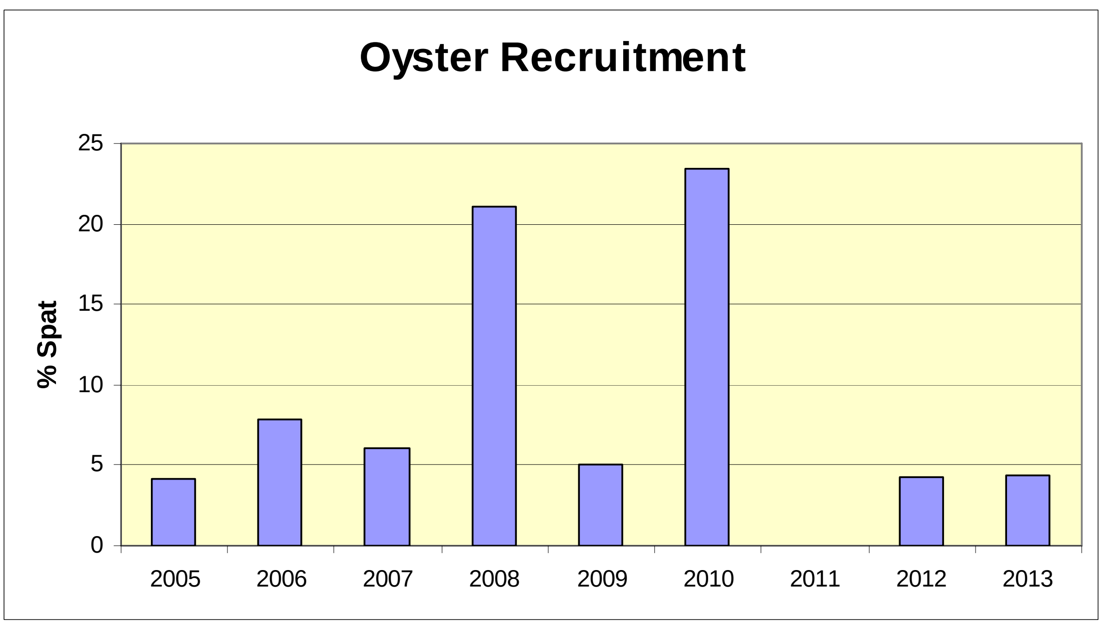

Figure 7.3.4b. Oyster recruitment as percent of spat observed in the subtidal oyster population in Chincoteague Bay, 2005-2013. No spatfall was observed in 2011.

Subtidal Oysters (cont'd)

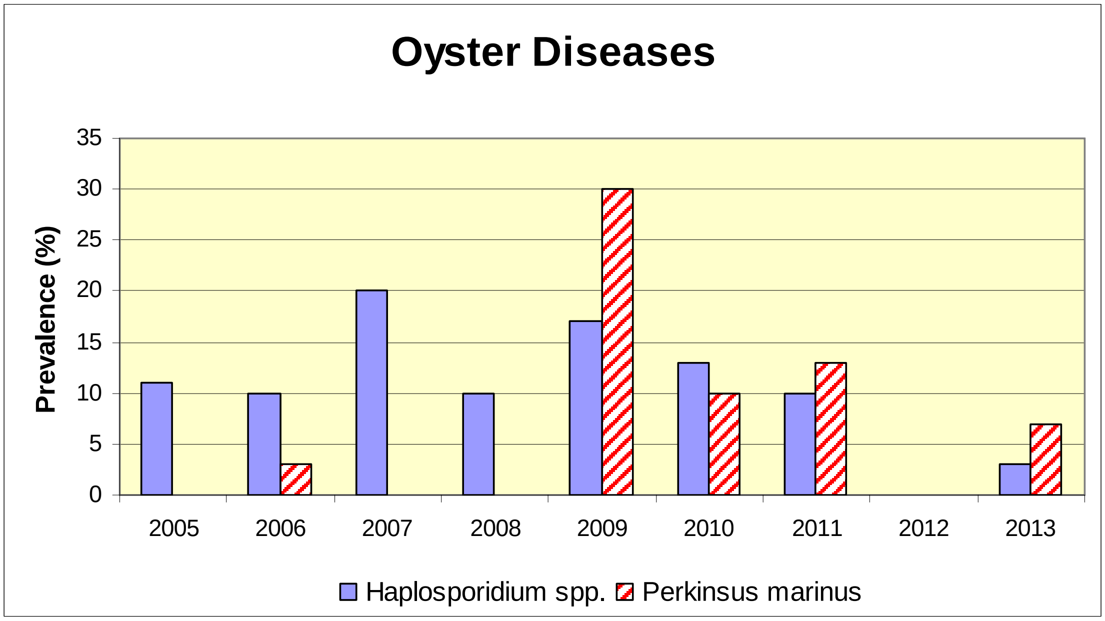

Figure 7.3.4c. Disease prevalence in the subtidal oyster population in Chincoteague Bay, 2005-2013. No disease was detected in 2012.

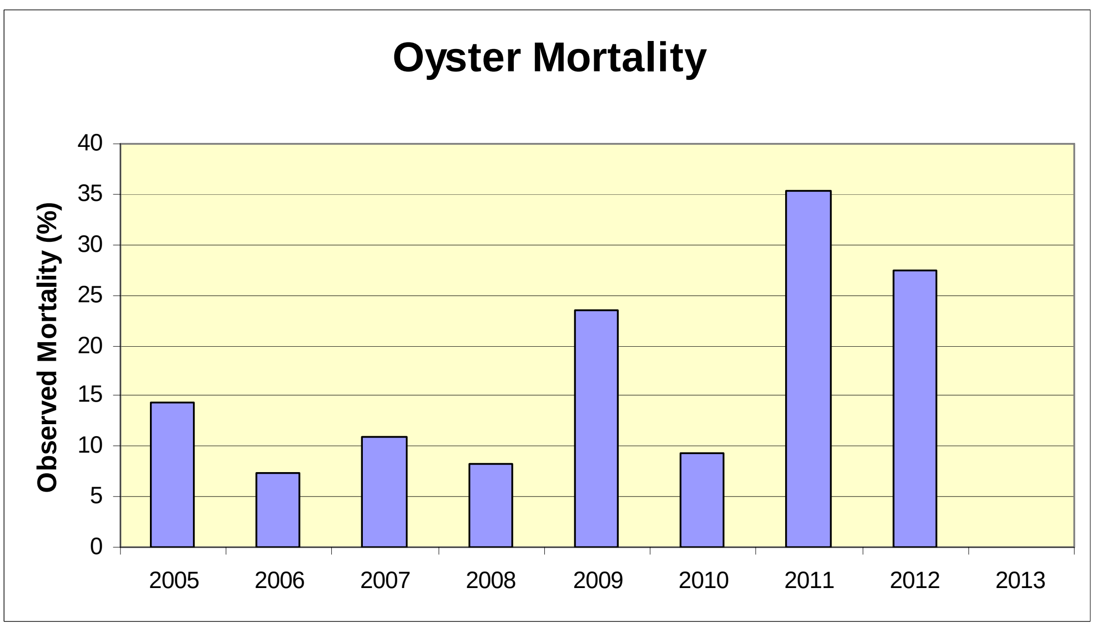

Figure 7.3.4d - Observed oyster mortalities in the Chincoteague Bay subtidal population, 2005-2012. Mortality data were not collected in 2013.

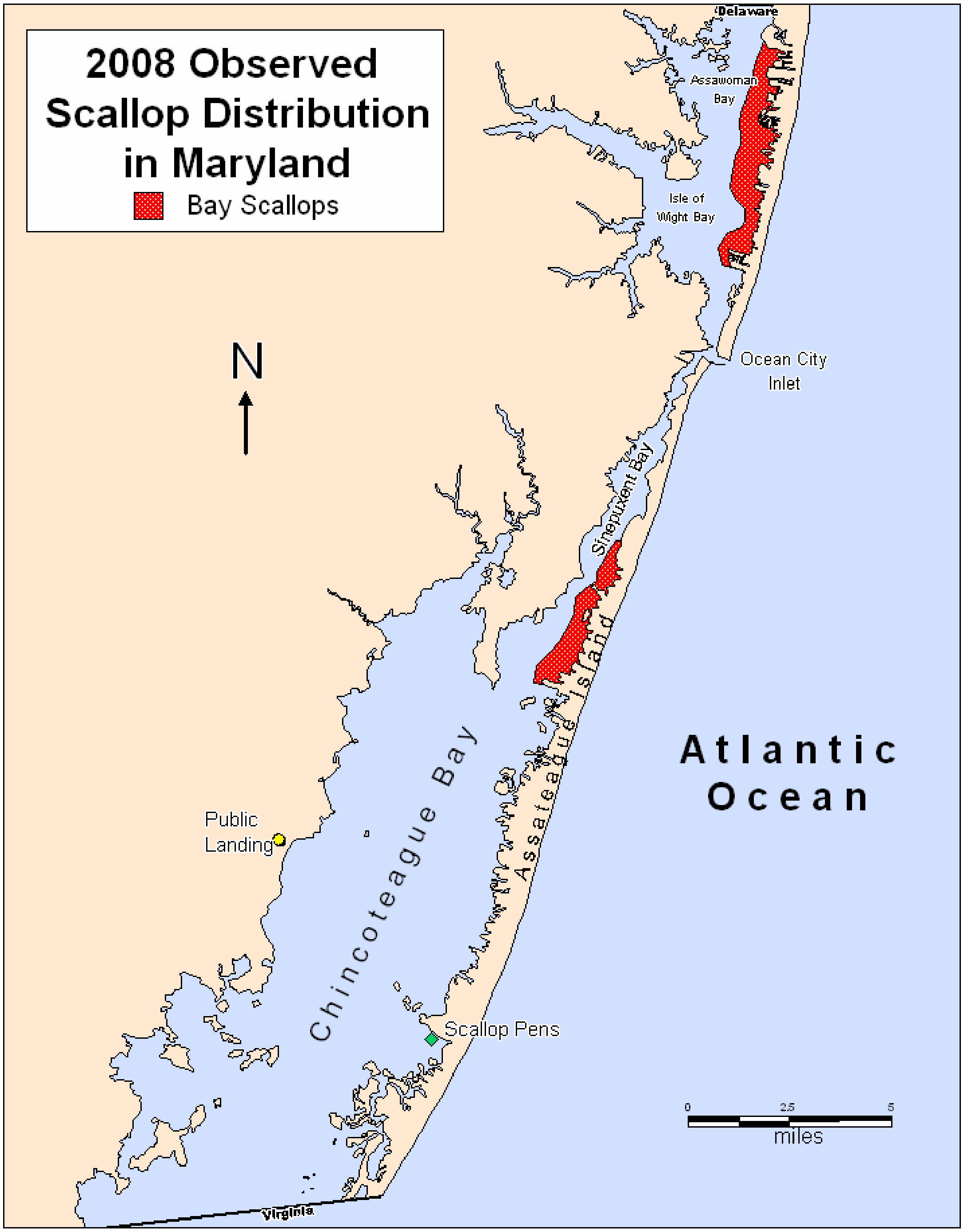

Figure 7.3.5 2008 observed scallop distribution area in the Maryland Coastal Bays.

Chapter 7.4

Summary of benthic community index results for the Maryland Coastal Bays

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Abstract
Benthic communities play an important role as food for fish and in cycling nutrients between the sediment and the water column. Benthic organisms were sampled and identified in the laboratory. The Mid-Atlantic Integrated Assessment (MAIA) benthic index was then calculated based on the abundance of species as well as the occurrence of certain tolerant or intolerant species. Open bays met the MAIA benthic index goal, while tributaries were degraded to severely degraded. Severely degraded sites either had few organisms and dominance of one species or had an unbalanced community heavily dominated by a small number of species, usually annelids. In general, the results of the 2010 benthic monitoring in the Maryland Coastal Bays were very similar to the results of previous years (2005 and 2006), suggesting unchanging benthic community conditions in Maryland's estuaries.

Introduction

Benthic communities play an important role as food for fish and in cycling nutrients between the sediment and the water column. The benthos is a good indicator of system health because they integrate conditions over time. Data used in this report focuses on data collected during the National Coastal Assessment (NCA) surveys 2000 and 2003.

Monitoring of benthic communities is currently not a long-term part of the monitoring program. Benthic monitoring data has been collected as part of U.S. EPA Environmental Monitoring and Assessment Program (EMAP) and EMAP-style monitoring programs (EMAP, Joint Assessment, MAIA and NCA).

Management Objective: Maintain healthy benthic communities.

***Draft* Indicator:** MAIA Benthic index > 3

Analyses
Analyses benthic community condition used the MAIA benthic index of biotic integrity which combines measures of abundance, number of taxa, Shannon-Weiner diversity index, percent dominance, percent abundance of pollution indicative taxa, percent abundance as pollution sensitive taxa, percent abundance of deep deposit feeders, percent abundance of Bivalves and the percent abundance ratio of Tanypodinae to Chironomidae (Llanso et al. 2002). Epifaunal organisms were eliminated from the analyses. The mean benthic index of 3.39 (met goal) was calculated by averaging results from 28 fixed stations visited in 2010.

Status of benthic community

Assawoman Bay

All sites met the benthic index goal in Assawoman Bay except the Greys Creek site (Figure 7.4.1). The Greys Creek site was degraded due to low diversity.

St. Martin River

The site in the lower mainstem of the river (XDN3724) met benthic index goal while sites in the prongs (SPR0009 and XDN4797) were either degraded or severely degraded (Figure 7.4.1). Site XDN3724 scored high for abundance and moderate for diversity and bivalves. The sites in the prongs scored low in every category. SPR0009 has been severely degraded in previous years, whereas the benthic condition of XDN4797 has varied depending on precipitation and river flow (Figure 7.4.1).

Site NCCA10-1614 in the St. Martin River was resampled one month after the initial visit. This site met the goal during the first visit, but was classified as degraded during the second visit. In both visits NCCA10-1614 exhibited large numbers of organisms above the upper abundance threshold possibly indicative of eutrophic conditions. The community was numerically dominated by small polychaete annelids (*Streblospio benedicti* and *Mediomastus ambiseta*) but the number of species was high. During the second visit no bivalves were found, and this caused the bivalve metric to score 1 and the site to fail the index. Because this difference is small, the site has been classified as meeting the goal in Figure 7.4.1.

Isle of Wight

All sites passed except upper Turville and Herring creeks (Figure 7.4.1). Turville Creek has been severely degraded in previous years and scored low for all parameters. While the Herring Creek site was degraded due to low taxa score. Manklin Creek had low diversity and high abundance.

Sinepuxent

The one site in Sinepuxent Bay met the benthic index goal with high scores in all categories (Figure 7.4.1).

Newport

The one site in the bay proper (XCM4878) passed the benthic index goal (Figure 7.4.1). The site in Newport Creek was found to be severely degraded. Newport Creek had mostly large abundance of organisms and were numerically dominated by oligochaetes, possibly indicating enriched organic conditions.

Chincoteague

All sites meet the benthic index goal (Figure 7.4.1). SitesNCCA10-1629, NPS 7 and NPS-10 scored high for bivalves while two sties (XCM0159 and XBM1301) scored low for abundance.

Summary

Open bays met the benthic index goal while tributaries were considered degraded to severely degraded. Sites that were severely degraded either had few organisms and dominance of one species or had an unbalanced community heavily dominated by a few species, usually annelids. Benthic condition in Isle of Wight and Chincoteague bays was good, largely unchanged from the last two previous years of monitoring (2005 and 2006). whereas the benthic condition of XDN4797, mouth of Bishopville Prong, has varied depending on precipitation and river flow.

Monitoring of regions subject to large environmental fluctuations are best monitored over time to assess the long-term response of the community and the relative influence of anthropogenic factors over the natural range of variability (Llanso *et al* 2002). The continuation of benthic monitoring in the Coastal Bays is an important indicator of ecosystem health.

Acknowledgements

Thanks to Kathy Dillow and Colby Hause, VERSAR, for overseeing all aspects of the field collection of samples.

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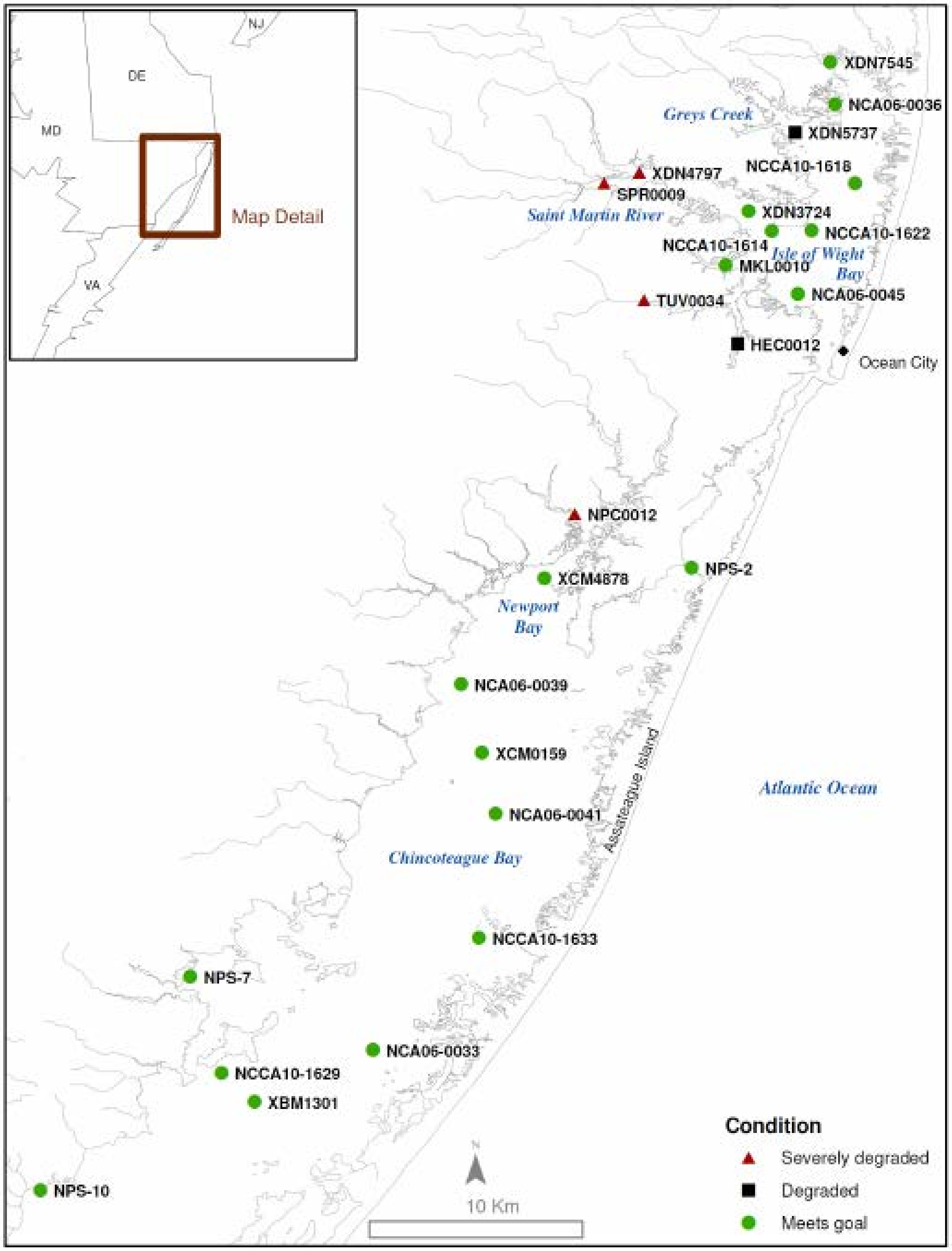

Figure 7.4.1 Benthic index of biotic integrity values calculated based on August 2010 survey for stations throughout the Coastal Bays.

Chapter 7.5

Status of Blue Crab, *Callinectes sapidus*, population in Maryland's Coastal Bays

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Abstract
The Maryland Department of Natural Resources (DNR) has conducted the Coastal Bays Fisheries Investigations (CBFI) Trawl and Beach Seine Surveys in Maryland's Coastal Bays since 1972, sampling with a standardized protocol since 1989. Although these gears target finfish, bycatch of crustaceans, mollusks, sponges and macroalgae are common. Geometric mean indices for blue crab developed from both the Trawl ($p = 0.20$) and Beach Seine ($p = 0.37$) Survey data varied without trend between 1997-2013. Both indices showed a time series high value in 2010 and low value in 2013. 2010 had a warm, wet spring, which provides prime conditions for coastal spawners that use the Maryland Coastal Bays as a nursery, such as blue crabs. In contrast, 2013 had a record-breaking cold winter, late spring, and a coast-wide severe late-spring storm, and subsequent late seagrass growth. Therefore, in 2013, conditions were poor for coastal spawners, and the Blue Crab indices reflect those environmental conditions.

The commercial harvest varied without trend in the time period 1997-2006 ($p = 0.14$) with a mean harvest of 1.24 million pounds per year and has varied without trend since 2007 ($p = 0.71$) with a mean harvest of 1.56 million pounds per year, ranging from 0.5 million pounds to 2.37 million pounds in 2010, the time series high since 1991. Additionally, there has been no trend in commercial harvest over the entire 1997-2013 time series ($p = 0.054$).

Data from the Trawl survey showed a strong seasonal trend in abundance, with a peak in June and dropping throughout the summer and fall. The Beach Seine Survey is only conducted in June and September, but showed the same relative difference in abundance between the two months. The Trawl Survey data also showed a significant difference in abundance among the four Coastal Bays, which appears to be related to mean depth and bottom dissolved oxygen, as there is are significant correlations with both factors ($p < 0.0001$)

Mean size of crabs caught in the CBFI Trawl Survey shows an increasing trend, both over the extended time period (1989-2013, $p<0.001$) and since 1997 ($p = 0.001$). A comparison study of Blue Crab mean length frequencies by gear type conducted in 2012-2013 to investigate if SAV beds in Maryland's Coastal Bays serve as critical habitat for fisheries resources, including crabs, showed significant differences ($p< 0.0001$). The mean length for Blue Crabs collected in the submerged aquatic vegetation, SAV, beds was the smallest (41.8mm) followed by beach seine (53.6 mm) and trawl (62.7 mm). The data suggest that the SAV beds provide habitat for small crabs measuring less than 40 mm in length. While small crabs were found in habitat without concentrated seagrass, this habitat appears to be most desirable for juvenile Blue Crabs.

The stability of the indices developed from the fishery-independent surveys, the stability of the commercial harvest, and the slight increase in mean size all suggest that the state of Blue Crabs in the Maryland Coastal Bays appears stable. The inter-annual variability of the abundance indicators reflects the biology of Blue Crabs as a coastal spawner, with population levels reflecting large-scale environmental factors.

Introduction

The Blue Crab, *Callinectes sapidus*, is a valuable resource to the Coastal Bays ecosystem and the commercial and recreational efforts it supports. As a coastal spawner, Blue Crabs in the Coastal Bays are simply a subset of a larger population that is subject to environmental factors operating at larger scales than this relatively small area. Therefore, DNR does not actively manage Blue Crabs in the Coastal Bays.

This report presents the state of the Blue Crab in the Coastal Bays as indicated by three factors – (1) fishery-independent indices of abundance, (2) commercial harvest and (3) mean size.

Abundance

DNR has conducted the Coastal Bays Fisheries Investigations (CBFI) Trawl and Beach Seine Surveys in Maryland's Coastal Bays since 1972, sampling with a standardized protocol since 1989 (Doctor et al., 2013). Although these gears target finfish, bycatch of crustaceans, mollusks, sponges, and macroalgae are common. Shore beach seine sampling is conducted at 19 fixed sites beginning in the second weeks of June and September to sample the shallow regions of the Coastal Bays frequented by juvenile fishes (Figure 7.5.1). Trawl sampling is conducted at 20 fixed sites with depths greater than 1.1 m (3.5 ft) from April through October (Figure 7.5.1). Physical and chemical data are documented at each sampling location. In both surveys, Blue Crabs are measured for carapace width, sexed and maturity status is determined. A subsample of the first 50 Blue Crabs at each site is measured and the rest are counted.

The distribution of crab catch from both surveys showed a strong right skew with less than 10% zero catches, so the geometric mean was developed as in index of relative abundance. Both the Beach Seine ($p = 0.37$) and Trawl Survey ($p = 0.20$) indices varied without trend between 1997-2013 (Figure 7.5.2 and 7.5.3).

Both indices showed a time series high value in 2010 and low value in 2013. 2010 had a warm, wet spring, which provides prime conditions for coastal spawners that use the Maryland Coastal Bays as a nursery, such as Blue Crabs. It should be noted that the Maryland Striped Bass Juvenile Index was also very high in that year (Durell and Weedon, 2011). In contrast, 2013 had a record-breaking cold winter, late spring, and a coast-wide severe late-spring storm, and subsequent late seagrass growth. Therefore conditions were poor for coastal spawners.

Data from the trawl survey showed a strong seasonal trend in abundance, with a peak in June and dropping throughout the summer and fall (Figure 7.5.4). The beach seine survey is only conducted in June and September, but showed the same relative difference in abundance between the two months.

The trawl survey data showed a significant difference in abundance among the four Coastal Bays, which appears to be related to mean depth and bottom dissolved oxygen, as there are significant correlations with both factors ($p<0.0001$).

Table 7.5.1 Mean Crab Count vs. environmental factors, from 1997-2013 data from the Maryland Department of Natural Resources, Coastal Bays Fisheries Investigations (CBFI) Trawl Survey

Bay	Mean Crab Count	Mean Site Depth	Bottom DO	Bottom Temperature	Salinity
Isle of Wight Bay	77	5.7	6.3	21.9	26.5
Chincoteague Bay	56	6.6	6.5	22.4	28.9
Assawoman Bay	38	7.4	6.5	21.8	27
Sinepuxent Bay	18	8.0	6.9	20.9	29.7

Commercial Harvest

Reported commercial harvest is the only fishery-dependent index available. Blue Crab recreational surveys have been conducted through Old Dominion University in 2001, 2002, 2005 and 2011, but all surveys were conducted only in the Chesapeake Bay, so do not provide information about Coastal Bays Blue Crab abundance.

The commercial harvest varied without trend in the time period 1997-2006 ($p = 0.14$) with a mean harvest of 1.24 million pounds per year (Figure 7.5.5). Harvest has varied without trend since 2007 ($p = 0.71$) with a mean harvest of 1.56 million pounds per year, ranging from 0.5 million pounds to 2.37 million pounds in 2010, the time series high since 1991. Additionally, there has been no trend over the entire 1997-2013 time series ($p = 0.054$).

Size

Mean size of crabs caught in the CBFI Trawl Survey shows an increasing trend, both over the extended time period (1989-2013, $p<0.001$) and since 1997 ($p = 0.001$, Figure 7.5.6).

A comparison study of Blue Crab mean length frequencies by gear type was conducted in 2012-2013 to investigate if SAV beds in Maryland's Coastal Bays serve as critical habitat for fisheries resources, including Blue Crabs. DNR expanded the CBFI to include stratified random sampling of SAV beds that had been present for at least five years as mapped in aerial surveys by the Virginia Institute of Marine Sciences Results showed mean lengths to be significantly different by gear type ($p < 0.0001$). The mean length for Blue Crabs collected in the seagrass beds was smallest (41.8 mm), followed by beach seine (53.6 mm) and trawl (62.7 mm). While small crabs were found in habitat without concentrated seagrass, this habitat appears to be most desirable for juvenile Blue Crabs.

Status of *Hematodinium perezi* in Maryland Coastal Bays

Histological assays of crab hemolymph from 2005 -2010 indicate the parasite continues to persist in crabs in the Coastal Bays ecosystem with seasonal variation (Figure 7.5.7, Messick unpublished data).

Molecular assays have been developed to detect the parasite in hemolymph, water and sediments. In May, July, and September 2006, and January 2007, crabs in Ocean City were sampled for *Hematodinium perezi* using a DNA-based assay (Nagle et al. 2009) to detect the genome of the parasite, *H. perezi*. Parasite DNA was present in July (37%), September (30%) and January (22%) (E.J. Schott and G.A. Messick, unpublished data). The polymerase chain reaction (PCR)-based prevalence was higher than prevalence as determined by histology, which agrees with Nagel *et al*. (2009). It is notable that even by PCR, *H. perezi* was not detected in May of 2006. Areas where the parasite was found in sediment and water tend to cluster along the Delmarva shoreline in areas like Johnson's Bay and Newport Bay (J.S. Pitula, unpublished data). This is interesting since these are areas closest to potential nutrient runoff. Approximately 10% of water and sediment samples from Maryland Coastal Bays ecosystem test positive for *H. perezi* using molecular assays (J.S. Pitula, unpublished). There may be hydrodynamic effects that influence infections. Recent molecular assays indicate that the parasite is found briefly in sediments and water in spring, followed by absence, then a strong presence during the summer. Summer detections may be consistent with sporulation from diseased crabs, but the spring detection may represent a free-living stage in the life cycle of the parasite (J.S. Pitula, unpublished).

Summary

The stability of the Blue Crab indices developed from the fishery-independent surveys, the stability of the commercial harvest of blue crabs in the Coastal Bays, and the slight increase in mean size all suggest that the state of Blue Crabs in the Maryland Coastal Bays is stable. The inter-annual variability of the abundance indicators appears to reflect large-scale environmental factors, typical of the biology of coastal spawners.

Figure 7.5.1 Sampling sites for the Maryland Department of Natural Resources Fisheries Service has conducted the Coastal Bays Fisheries Investigations (CBFI) Trawl and Beach Seine Survey.

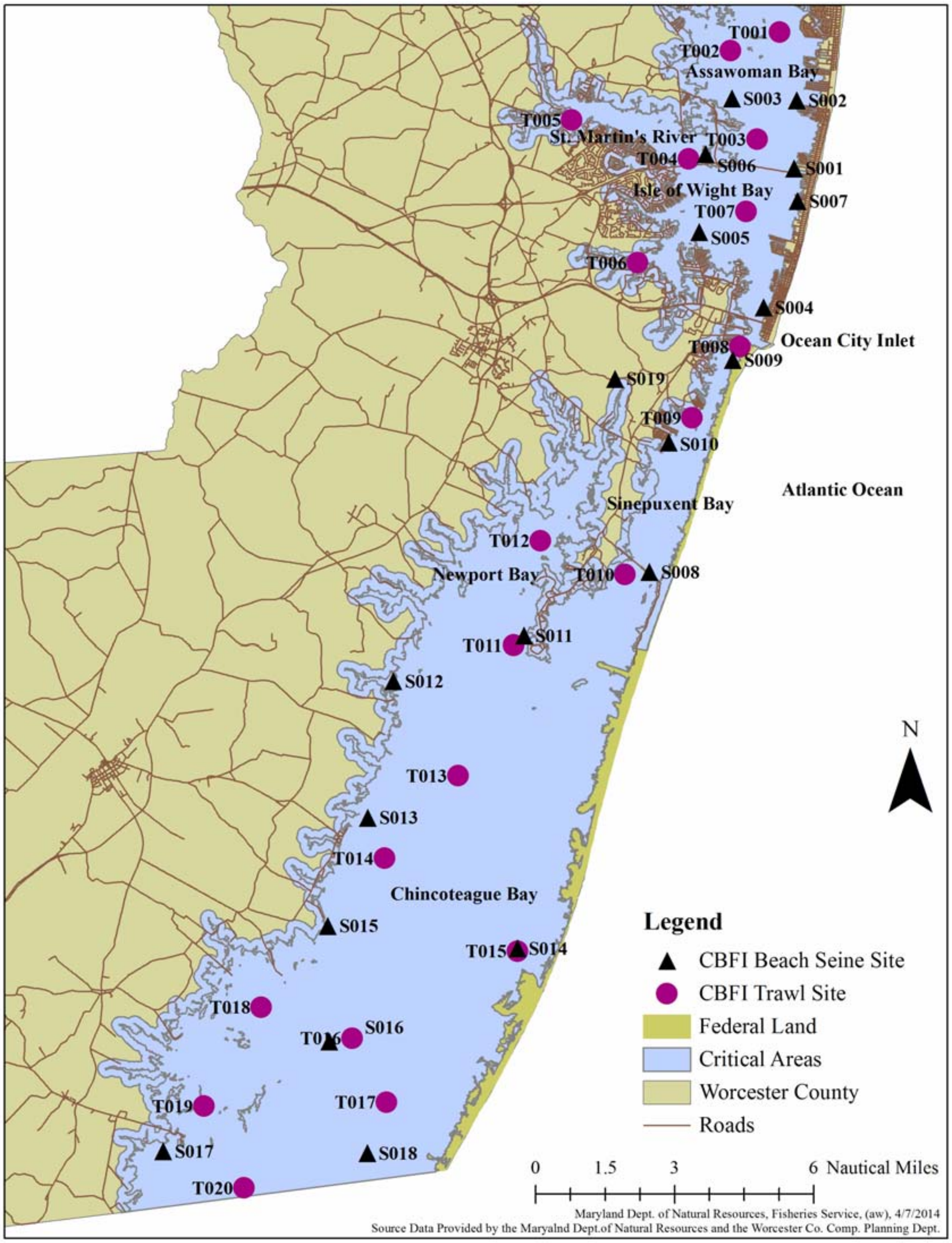


Figure 7.5.2 Annual Time Series of Geometric Mean Index of Abundance with 95% confidence interval, developed from Maryland Department of Natural Resources Fisheries Service Coastal Bays Fisheries Investigations Beach Seine Survey data.

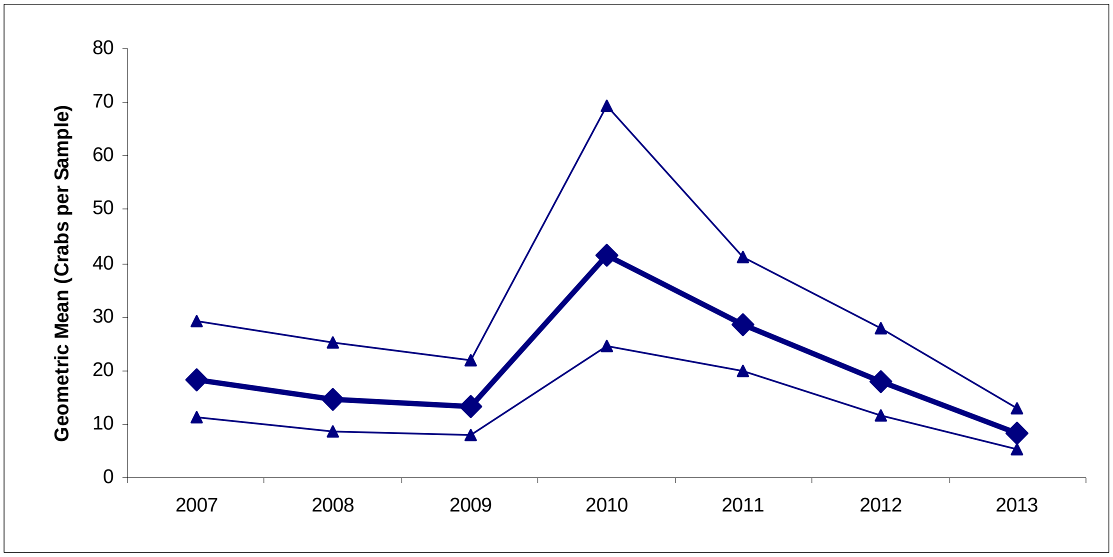


Figure 7.5.3 Annual Time Series of Geometric Mean Index of Abundance with 95% confidence interval, developed from Maryland Department of Natural Resources Fisheries Service Coastal Bays Fisheries Investigations Trawl Survey data.

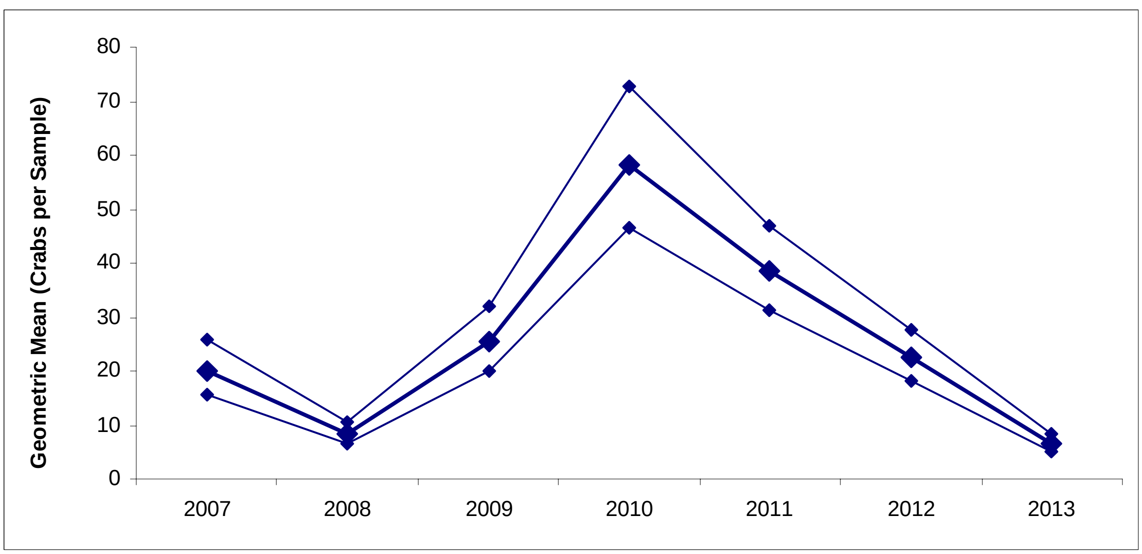


Figure 7.5.4 Monthly Mean Crabs per Sample with 95% confidence interval (2007-2013), developed from Maryland Department of Natural Resources Fisheries Service Coastal Bays Fisheries Investigations Trawl Survey data.

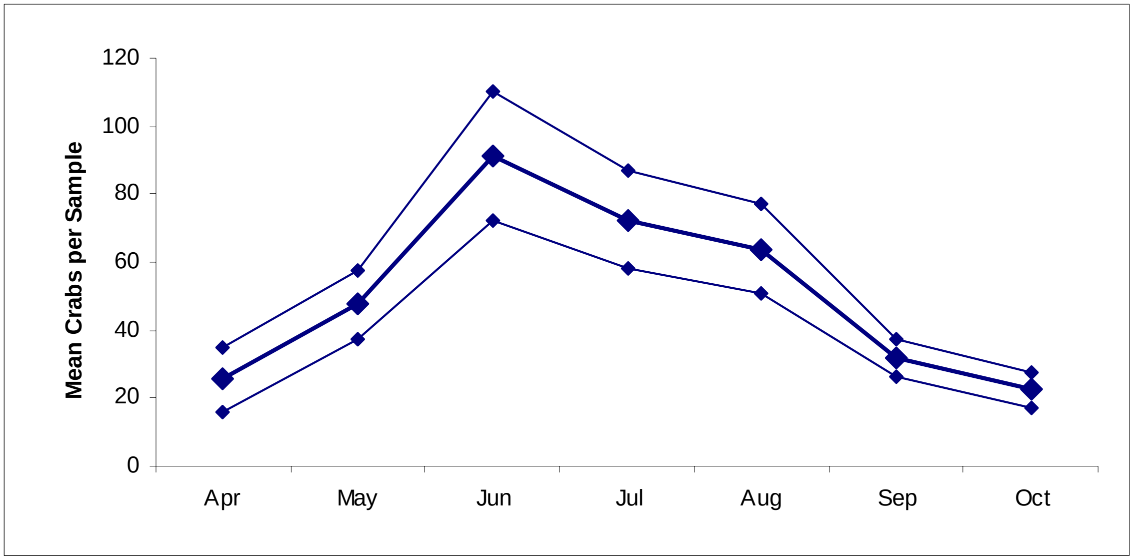


Figure 7.5.5 Annual harvest of Blue Crab Commercial Harvest in Maryland's Coastal Bays (1997-2013).

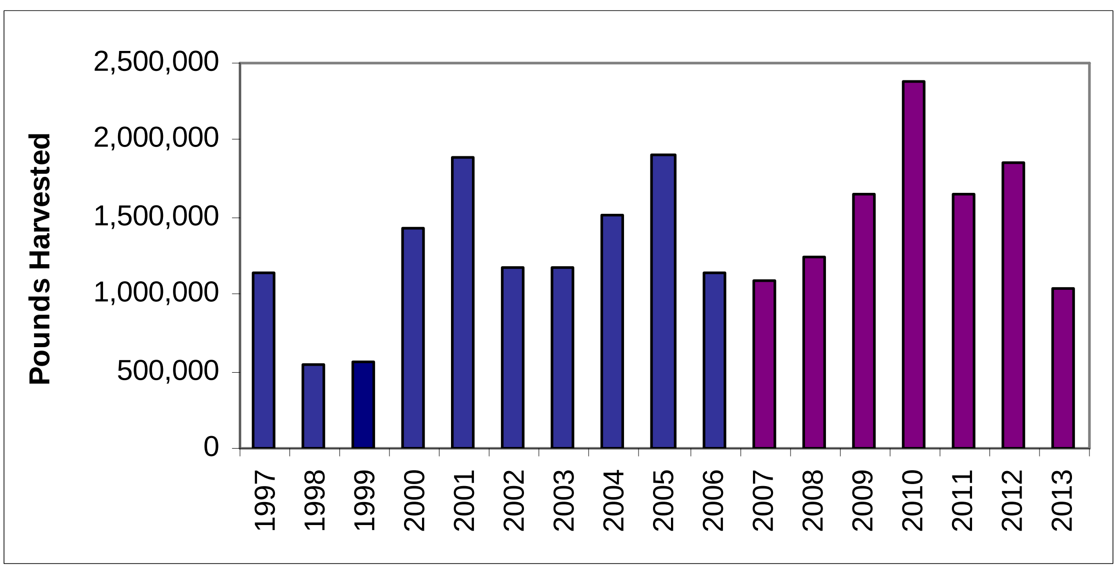


Figure 7.5.6 Time Series of Mean Carapace Width with 95% confidence interval (1997-2013), developed from Maryland Department of Natural Resources Fisheries Service Coastal Bays Fisheries Investigations Trawl Survey data.

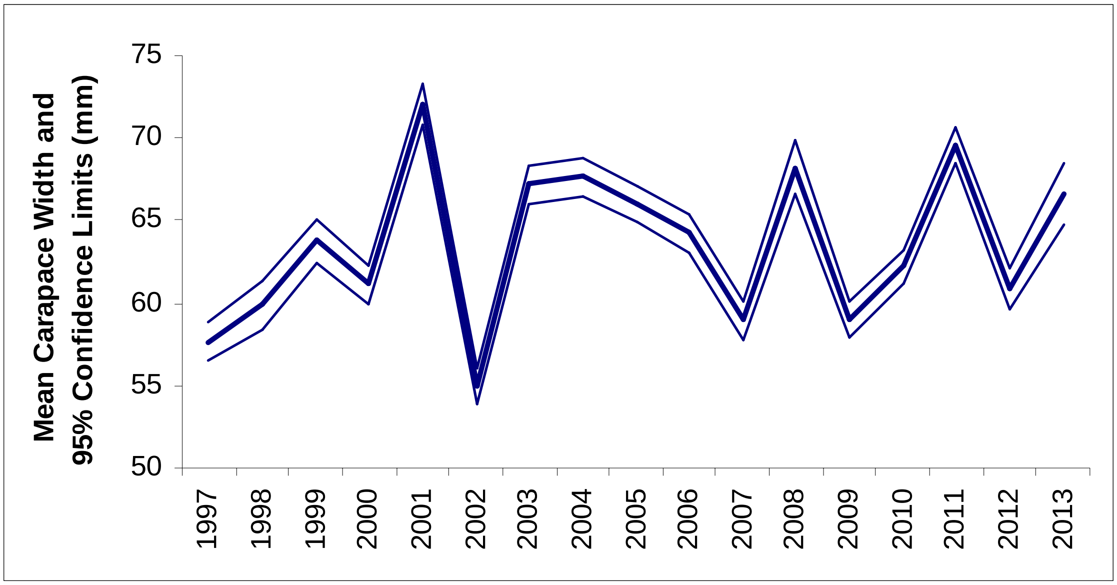
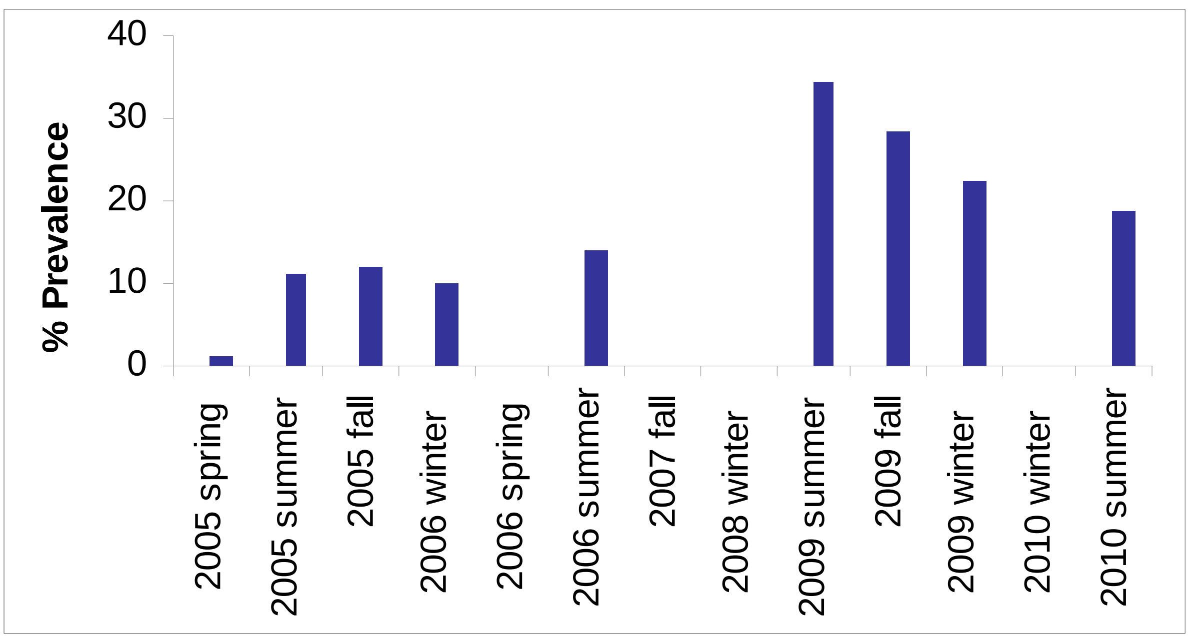


Figure 7.5.7 Time Series of percent prevalence of *Hematodinium perezi* developed from Maryland Department of Natural Resources Fisheries Service Coastal Bays Fisheries Investigations Trawl Survey data.



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Chapter 7.6

State of Horseshoe Crabs in Maryland Coastal Bays

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Abstract
Horseshoe crabs and their eggs are a critical food source for many species including sharks, turtles and shore birds. Commercially the species is harvested for bait and for a protein in their blood, Limulus Amebocyte Lysate, which is valuable and widely used in the biomedical industry. Development of coastal habitat is the major threat to the population. Shoreline armoring and erosion decreases available spawning habitat. An annual spawning survey was initiated in 2002 to determine spawning habitat and crab abundance. The Interstate Fishery Management Plan for Horseshoe Crabs recently reduced allowed harvests and established a horseshoe crab sanctuary at the mouth of the Delaware Bay.

Introduction
Horseshoe crabs, *Limulus polyphemus*, are characterized by high fecundity, high egg and larval mortality, and low adult mortality (Botton & Loveland, 1989; Loveland, et al, 1996). They spawn multiple times per season and per tide, laying approximately 3,600 to 4,000 eggs in a cluster (Schuster, 1950; Shuster & Botton, 1985). Based on different methods of estimating maximum age, adults may live as long as 16 to 19 years.

Populations are influenced by harvesting levels, habitat loss and shorebird predation. During the first half of the 20th century, threats to the horseshoe crab included overharvesting primarily for fertilizer and animal feed. Large numbers of crabs were collected on Mid-Atlantic beaches or in nets during the spawning season to meet this demand. However, most of the evidence of over-harvesting is anecdotal because historical data on horseshoe crab harvests is often incomplete. Watermen were not required to report their catch until the late 1990's.

The threats to horseshoe crab populations have changed dramatically as a result of expanding fisheries. Since the early 1990's, horseshoe crabs have been harvested for bait to catch American Eel (*Anguilla rostrada*) and whelk (*Busycon spp*.) in Maryland and the rest of the Mid-Atlantic region. The increases in horseshoe crab harvests throughout the late 1990's are a result of an expanding whelk fishery. Increasing demand for whelk in Asian and European markets was the driving force behind the expansion. In addition, horseshoe crabs are used for the biomedical industry and have lost valuable spawning habitat to coastal development.

Additionally, this species is harvested by the biomedical industry to produce a valuable medical product critical to maintaining the safety of many drugs and devices used in medical care. A protein in the blood called Limulus Amebocyte Lysate (LAL) is used by pharmaceutical and medical device manufacturers to test their products for the presence of endotoxins, bacterial substances that can cause fevers and even be fatal to humans. A horseshoe crab's blood has a blue to blue-green color when exposed to the air. The blood is blue because it contains a copper-based respiratory pigment called hemocyanin.

Development of coastal habitat has increasingly become an important issue for horseshoe crabs. Sandy beaches are essential spawning habitat for horseshoe crabs and nearshore shallow water habitats (i.e., mud and sand flats) are important nursery grounds for juvenile crabs. Human activities can reduce the available habitat horseshoe crabs need for reproduction and larval development to maintain their populations over time. Several types of shoreline erosion control structures commonly used to protect property reduce available spawning habitat. These structures include bulkheads, groins and rip rap. Each of these shoreline control structures commonly referred to as "armoring" or "hardening", is designed to protect the shoreline from the effects of erosion. However, they also block access to spawning beaches, eliminate sandy beach habitat or entrap and strand spawning crabs during times of high wave energy. Coastal development activities combined with shoreline erosion are contributing to the continued deterioration of coastal habitats essential to spawning horseshoe crab populations.

Data Sets

Cooperative Horseshoe Crab spawning study since 2002 Maryland Coastal Bays Program, Maryland Department of Natural Resources, and volunteers

Horseshoe Crab Indicator

None

Status of Horseshoe Crab

The Interstate Fishery Management Plan (FMP) for Horseshoe Crabs was approved by the Atlantic States Marine Fisheries Commission (ASMFC), on October 22, 1998. The fishery management plan is designed as a tool to guide individual States to conserve and protect the horseshoe crab resource at a population that sustains its ecological and economic benefits. Contained within the fishery management plan are requirements for managing the horseshoe crab harvests and monitoring populations.

Requirements of the Horseshoe Crab fishery management plan Addendum 1 include:
- States must reduce horseshoe crab landings to 25% below their reference period landings.
- States with more restrictive harvest limits are encouraged to maintain those limits.
- Encourage the National Marine Fisheries Service (NMFS), to establish a horseshoe crab sanctuary at the mouth of the Delaware Bay estuary.

The FMP has been through several addendums that have refined the harvest levels and allocation between states. Most recently addendum VII was approved in February 2012 (ASMFC 2012). This addendum implemented the Adaptive Resource Management (ARM) Framework for use during the 2013 fishing season and beyond. The framework considers the abundance levels of horseshoe crabs and shorebirds in determining the optimized harvest level for the Delaware Bay states of New Jersey, Delaware, Maryland and Virginia (east of the COLREGS).

In 2013 a stock assessment update was completed by the Horseshoe Crab Stock Assessment Subcommittee. It was a trend analysis and overfishing definitions were not defined because of data limitations. The analysis determined that there were regional specific trends in Atlantic Coastal Horseshoe Crab abundance. For the Delaware Bay region, which Maryland is associated with, there was evidence for demographic-specific increases in abundance through the time series of data, but trends have been largely stable since the 2009 stock assessment.

Summary

Horseshoe crab spawning varies by latitude but generally occurs between May and July along the Atlantic coast. An annual, localized spawning survey was initiated in 2002 to better determine spawning habitats and crab abundance. The Maryland Coastal Bays survey was initially set up to mirror the same time frame as the Delaware Bay horseshoe crab spawning surveys (May and June) to allow for comparisons. Spawning in the Maryland coastal bays typically peaks in June, and often continues throughout July. Since the noticeable temporal range of spawning is longer than this initial sampling period, the surveys have been extended into July since 2007. Twelve annual surveys, 2002-2013, have resulted in 700 documented observations and a sum total of 145,168 horseshoe crabs (Table 7.6.1).

Table 7.6.1 Summary of horseshoe crab counts over time.

Total # of Horseshoe Crabs counted by month and year					
YEAR	May	June	July	Aug	Grand Total
2002	0	105			105
2003	2	521			523
2004	57	632			689
2005	48	261			309
2006	125	3,793			3,918
2007	711	6,636	270		7,617
2008	1	4,689	5,928		10,618
2009	10	18,627	3,190	19	21,846
2010	1,205	17,285	4,948		23,438
2011	5	15,166	7,934		23,105
2012	2,032	13,330	5,748	17	21,127
2013	261	22,875	8,737		31,873
Grand Total	4,457	103,920	36,755	36	145,168

The majority of crabs, 119,080 (82%), were observed to be spawning at or within one meter of the high tide line. It was noted that during the highest spawning activity along Skimmer Island that a substantial number of the crabs were spawning 2 or more meters out along the shoreline. These results only reflect those estimates for $1m^2$ of the high tide line to be consistent in surveying methodology, and therefore the estimates of total crabs on the beach during high density spawning are lower than actually observed.

The survey counts over the dozen years indicate a gradual increase in male to female ratios particularly in 2006 and 2009, and have remained relatively stable (Table 7.6.2). In 2013, we found 3.6 males to every female crab. This is important for maintaining genetic diversity. Harvest regulations in Delaware Bay, Maryland and Virginia have capped the number of female horseshoe crabs that can be harvested. This data indicates that male biased harvest in recent years has not had an effect on the local spawning population's ratio.

Table 7.6.2 Total number of male and female horseshoe crabs and sex ratio by year.

	Males (M)	Females (F)	M:F ratio
2002	67	38	1.8:1
2003	314	209	1.5:1
2004	438	251	1.8:1
2005	182	127	1.4:1
2006	2,939	979	3.0:1
2007	5,799	1,818	3.2:1
2008	8,289	2,329	3.6:1
2009	17,551	4,295	4.1:1
2010	18,642	4,796	3.9:1
2011	18,508	4,597	4.0:1
2012	16,872	4,255	4.0:1
2013	24,876	6,997	3.6:1

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Chapter 7.7

Status of the Threatened Piping plover, *Charadrius melodus*, population in the Maryland Coastal Bays

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Abstract

Assateague Island forms 22 miles of the eastern edge of the Maryland Coastal Bays. Managed primarily for natural coastal processes, the island influences tidal exchange, supports an array of terrestrial, wetland and aquatic communities and provides clean sandy sediments. Coastal storm tides that maintain the island's integrity result in the formation of habitats that support Piping plovers (*Charadrius melodus*) a Federally Threatened species. However, post-storm features eventually develop into more stable terrestrial communities that do not support this species. When Piping plovers were listed as a Threatened species, the Maryland breeding population was around 20 pair. Following a series of storm tidal events in the 1990s, the population tripled to around 61 pair. A recent lapse in strong storm surges has allowed plover habitat to wane, resulting in a decline to around 43 breeding pair.

Background

Assateague is one of the very few east coast barrier islands where natural coastal processes are allowed to occur largely unimpeded by human activities. Natural processes include the action of tides, wind, waves, currents, storms, and sea level rise which influence and shape the terrain of the barrier's terrestrial communities and adjacent aquatic habitats.

In response to these processes, Assateague Island is transgressing to the west via cross-island sand transport, a product of storm overwash. Many of the Island's terrestrial habitats are in a constant state of flux as these processes alter physical conditions and disrupt plant succession. The overwash action creates its own signature features that have become increasingly important to regional biodiversity as shore stabilization activities elsewhere along the Mid-Atlantic prevent natural habitat formation processes. The majority of rare, Threatened and Endangered species utilizing Assateague are linked to the sparsely vegetated washover habitats created and maintained by storm tide flooding.

Piping plovers (*Charadrius melodus*), a Federally Threatened species (U.S. FWS, 1996), restricts its breeding in to early successional coastline habitats that only occur on Assateague Island.

These habitats include the range of sediment transfer and depositional features that result from lunar and storm tides. They include seasonal ocean beach, winter debris wracks/storm berm, backshore beach, dune runnels, surge channels, washover fans, washover aprons, intertidal lagoon/bay beaches and emerging sand flats. These features may overlie existing vegetated communities capable of re-emerging, but they also carry transported seed and roots that can germinate under favorable soil conditions. Based on site conditions, washover deposits will usually support succession through a variety of plant species starting with the first growing season. The timing of subsequent tidal disruptions will determine the longevity of these communities.

The value of these features to Piping plovers is based on the bird's biological need for open surfaces for nesting, foraging and visibility of predators. The need for available forage is paramount and dependent on the biotic richness of the deposited sediment. Sediment transported from near shore bars can retain aquatic infauna remains. The erosion and transport of terrestrial vegetation also adds organic materials. Washover deposition with incorporated debris will support detritivores and scavengers, some of which will spend part of their life cycle on the exposed surface.

Piping plovers forage on surface-dwelling prey, which they find by sight. By sampling prey at plover foraging locations and random sparsely vegetated features, it is apparent that plovers preferentially select foraging locations with abundant prey (Loegering, 1992). Those locations are mainly major sediment deposition sites that are low enough to maintain soil moisture from a near-surface fresh water lens. This cross-island foraging habitat for Piping plovers is unique to Assateague Island on the East Coast. Competition for good foraging locations can lead to aggression to the point of injury to other adults and chicks. Later breeding or subordinate pairs use substandard foraging habitat, which can result in their chicks taking longer to develop flight ability.

Moist, sparsely vegetated features with occasional overwash or tidal action continue to host foraging plovers over multiple seasons. Moist sites maintained only by rain or a ground water lens show a gradual decline in use, while deposition features that dry out are only used for nesting. Habitat mapping over time shows the expansion of overwash features after significant tidal events and the contraction of sparsely vegetated features into vegetated communities when storm frequency or intensity decline. Annual mapping of plover nests and brood locations confirm the fidelity to high quality washover features. When the number or area of these features retracts, the reduced capacity to support successful plover breeding can be anticipated in the returning breeding population.

Besides food, the other necessary component for successful breeding is the nest site. Plover coloration is suited for nesting in a sand/shell substrate. Any of the dry, open habitats described above are suitable for plover nesting. Fortunately, overwash seldom occurs during the breeding season. Pairs usually select a nesting site close to their anticipated foraging area. The majority of nests are placed on open sand. Occasionally they will utilize individual plants or low lying, low density plant communities. With the availability of dune fields and former, dried up washover fans, nesting habitat is available essentially everywhere on Assateague. The critical need for the breeding pair is the forage location.

Data Sets
Monitoring of piping plover breeding success on Assateague Island National Seashore has been conducted since the species was federally listed as Threatened in 1986. The Atlantic Coast Piping Plover Recovery Plan (USFWS 1996) provides specific information on the species and recommends monitoring goals and management actions. Primary management objectives include limiting human disturbance and providing protection from predators. Monitoring efforts include surveys to document the breeding population and observations to estimate reproductive productivity.

The monitoring program splits the plover reproductive activities into two phases: nest and incubation activities, from which breeding population size is estimated, and hatching and fledging activities from which reproductive success is estimated. The size of the breeding Piping plover population is estimated from data collected on nesting activity. The monitoring program also completes a single annual census, standardized on the East Coast to occur during the first 10 days in June.

Analyses
Population estimates and breeding success as well as mapping of plovers and habitat.

Management Objective:
Maintain a breeding population of the threatened Piping Plover on Assateague Island.

Status of piping plover breeding population

Significant tidal events through the 1990s have resulted in westward island migration along several sections of Assateague Island. The remaining landscapes of potential plover foraging habitat resulted in a tripling of the local population, from a 7 year pre-storm mean of 20 pair (1986-1992), to a 12 year post-storms mean of 61 pair (1996-2007).

Major tidal events were not experienced along Assateague from 2000 until 2009. Sparsely vegetated habitat resulting from the 1990s events decreased slowly over time. The critical features lost over this time were the surge channels, washover fans and washover aprons. All converted to dune fields or dense vegetated communities which prohibited plover chicks from reaching the remaining foraging habitat along the island's open bayside habitats (Figure 7.7.1).

In 2007 the breeding population was still high with 64 pair. The breeding population began to drop in 2008 (49 pair). Storms in 2009 (Ida) and 2012 (Sandy) produced minor washover features that reached only about 200 meters west of the winter storm berm. While the numbers of discrete washover fans from both storms were rather small, each fan was occupied by plover breeding pairs during each season. The washover fans from both events appear to have provided habitat to maintain a breeding population that averaged 43 pair (2008-2013). Observations and subsequent mapping indicate that washover fans from Hurricane Sandy are already transitioning through vegetative succession.

Summary
Piping plovers migrate up the eastern seaboard each spring looking for a mate and favorable breeding conditions. Adults tend to return to the same site after a successful breeding season. On Assateague Island, potential plover breeding habitat undergoes a change each winter season: the habitat undergoes flooding or it becomes more stable. As plovers arrive in the spring, older birds may claim their former locations, while other birds search out new or existing forage habitat. The birds pick sites in anticipation that forage will be available in three months when chicks will hatch. The winters leading up to 2007 lacked significant storm tides and Assateague had less high quality breeding habitat. The reduction of foraging habitat led to a gradual decline in breeding adults. Assateague's capacity to maintain breeding adults and attract new breeding stock will depend on the near-term tidal processes and local storm climate.

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A **B**

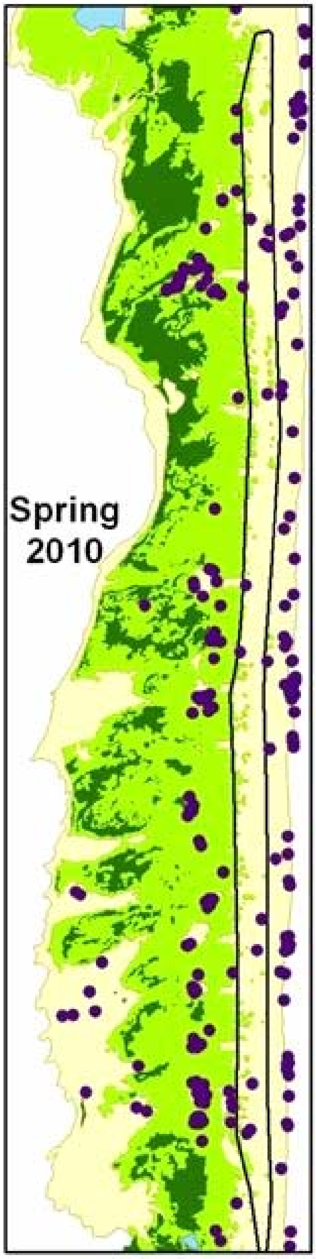

Figure 7.7.1 Brood movement of Piping Plovers on Northern Assateague in 2014 (A) and 2010 (B). The effects of the berm (black outlined area) are shown in panel B.

Chapter 7.8

Avifauna of the Maryland Coastal Bays

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Abstract
Between 2007 and 2013, of the 447 (426 non-pelagic) bird species occurring in Maryland, over 360 (80%) (332 non-pelagic, 78%) have been recorded in Worcester County (eBird), which contains the entire Maryland Coastal Bays watershed. The juxtaposition of a variety of habitats along a major migratory flyway results in this high diversity of avian fauna. Much of the diversity is directly linked to the presence of shallow water habitats, including marshes, mudflats, seagrass beds, and islands, that do not occur in nearby inland areas. These provide food, and breeding and overwintering habitats for aquatic bird species. Additional habitat types found within the watershed include forests, essential to forest-interior-dwelling breeding species; shrub and scrub; and agricultural grassland areas.

Introduction

Breeding, wintering and migratory waterbirds are integral resources of the Coastal Bays. Waterbirds feed at the top of food chains, and have specialized habitat requirements for successful reproduction. Their population health is an important indicator for evaluating ecosystem conditions. Development-related habitat degradation and loss, chemical contamination, fisheries over-harvesting, and sea level rise are some of the major factors impacting waterbird population trends.

Colonial nesting waterbirds comprise both resident and migrant species which depend on the Coastal Bays watershed for critical breeding habitat and food sources. For some species, these habitats are scarce or non-existent in other Maryland regions.

Most species of shorebirds are long distance migrants, breeding in the taiga or tundra area of northern Canada and Alaska, and wintering from the southern United States through South America. In recent years the importance of migratory stop-over areas, including the Maryland Coastal Bays, has become apparent. Here is where they refuel for their energy demanding migrations. The high productivity of the ocean beaches, salt marshes, and tidal flats along Maryland's coast all provide foraging habitat for shorebirds during both the spring and fall migrations.

Migratory waterfowl breed in the northern United States and North American tundra, and over-winter in lakes, bays and rivers, including the Coastal Bays. The area supplies abundant food resources, including finfish, shellfish and vegetation, in waters that typically remain open throughout the winter.

Datasets

Maryland Department of Natural Resources Colonial Nesting Waterbird Census – Breeding pair counts of colonial nesters have been conducted annually since 1985. Black skimmers, royal terns, and Forster's terns were fully censused yearly. Other species were fully censused every 5 years beginning in 1998; intervening years were partial censuses.

Maryland Department of Natural Resources Mid-Winter Waterfowl Survey – The Mid-Winter Waterfowl Survey has been conducted since 1935, throughout the United States. It is not based on a statistical sampling plan and some wintering habitats are not covered, so results are best used for relative abundance and distribution on wintering habitats for most species (Eggeman & Johnson, 1989). In Maryland, it is conducted aerially during January, using observer counts from fixed-wing aircraft, and covers the Chesapeake and Coastal Bays. Flight routes are not standardized. Statewide data since 1955 are available on-line from the U.S. Fish and Wildlife Service, USFWS, and the Maryland Department of Natural Resources; however, Coastal Bays specific data were available only as hard copy from Maryland DNR Wildlife and Heritage Service (Hindman, pers. comm.)

Ocean City Christmas Bird Count - The Christmas Bird Count is a 1-day census held each December. The Ocean City count has been held since 1948, within a 7-mile radius circle centered on Berlin. It includes the Pocomoke River watershed as well as a portion of the Coastal Bays. Counts are made by volunteer birders by land and occasionally by boat. As such, differences in effort can influence count results year-to-year. Total species count data for each CBC circle are available from Cornell University; however, the Ocean City count is divided into territories that allow removal of most birds counted outside the Coastal Bays watershed. These parsed data were obtained from the Ocean City CBC compiler (Sheppard, pers. comm.).

eBird - A real-time, online checklist program, eBird has transformed how the birding community reports and accesses information. Launched in 2002 by the Cornell Lab of Ornithology and National Audubon Society, eBird provides rich data sources for basic information on bird abundance and distribution at a variety of spatial and temporal scales. eBird documents the presence or absence of species, as well as bird abundance, through personal checklist data typically submitted by the extensive community of amateur birders in the United States.

Management Objective: To maintain suitable bird populations.

Indicator 1: Maintain shorebird populations

Indicator 2: Maintain colonial nesting waterbird populations

Analyses and Results

Colonial Nesting Waterbirds

Colonial nesting waterbirds that find essential habitat in the Coastal Bays include herons, egrets, gulls, terns, skimmers, cormorants, pelicans and ibises. Nesting pairs in Maryland were counted periodically beginning in 1985. Population trends for the three species censused annually were determined and compared to baseline data from 1977. Black Skimmers have shown a precipitous decline in the number of breeding pairs over the long-term, particularly early in this century. An encouraging 4-year increase 2007-10 was not maintained, and the number of pairs has remained <30 since 2005 (Figure 7.8.1). Royal terns show a modest increasing trend long-term, but have been in steady decline since 2009 (Figure 7.8.2). No long-term trend was found for Forster's terns, with the number of pairs and the number of colonies both widely variable between 2007-13 (Figure 7.8.1).

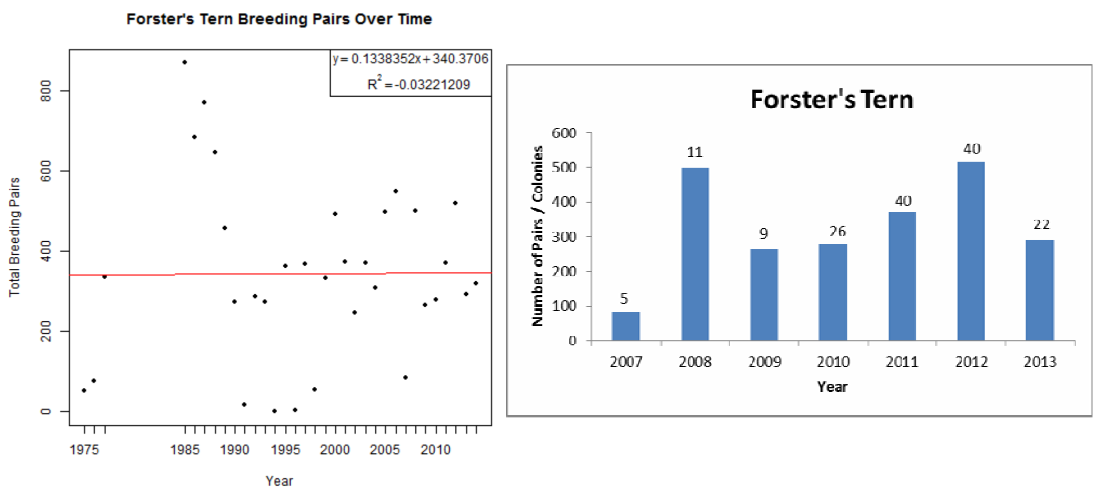


Figure 7.8.1 Long-term trend and recent status of Forster's tern nesting pairs in Maryland Coastal Bays.

Four additional colonial nesting species were censused periodically between 2007-13. Brown Pelicans and Double-crested Cormorants nest in trees, while the two species of tern nest in ground scrapes. Brown Pelicans nested on South Point Spoils until 1995. They did not nest in the Coastal Bays again until 2005, when they colonized Big Bay Marsh; however, that colony held no pairs during 2013. The Least Tern is federally endangered. From a total of 10 colony sites used since 1987, only three held nesting pairs between 2007-13, with most pairs found on the north end of Assateague Island. (Figure 7.8.2)

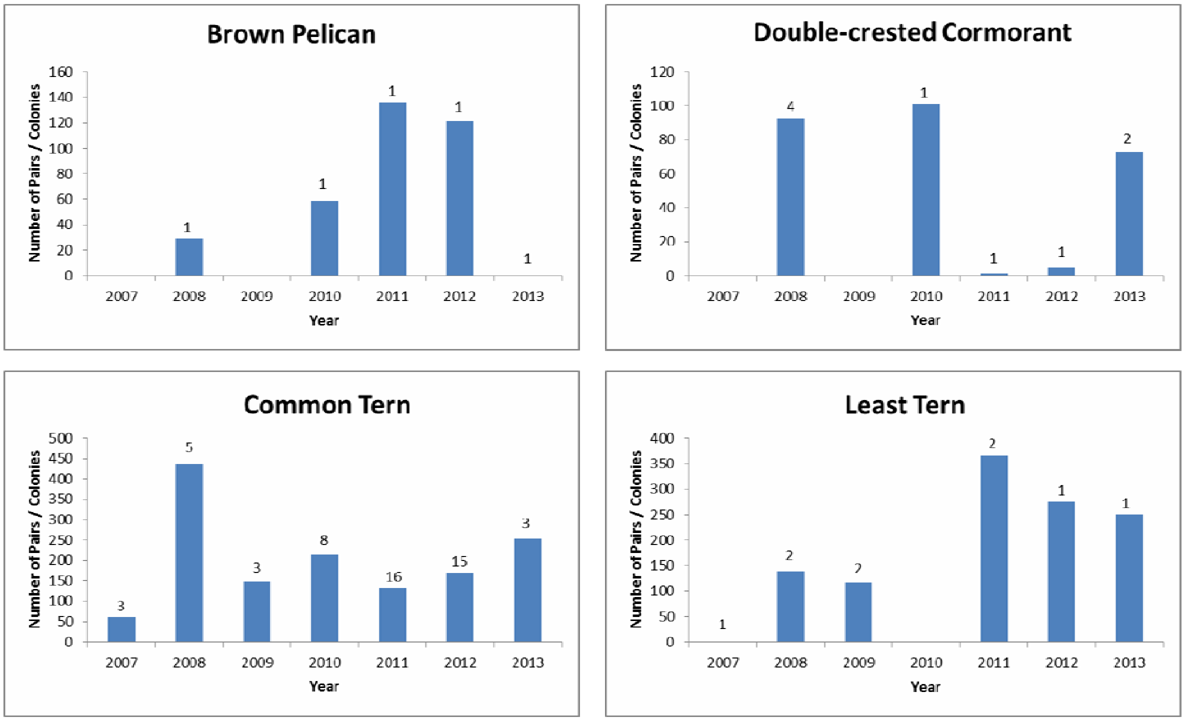


Figure 7.8.2 Recent status of 4 species of colonial nesting waterbirds in Maryland's Coastal Bays (2007-2013).

Migratory (wintering) Waterbirds

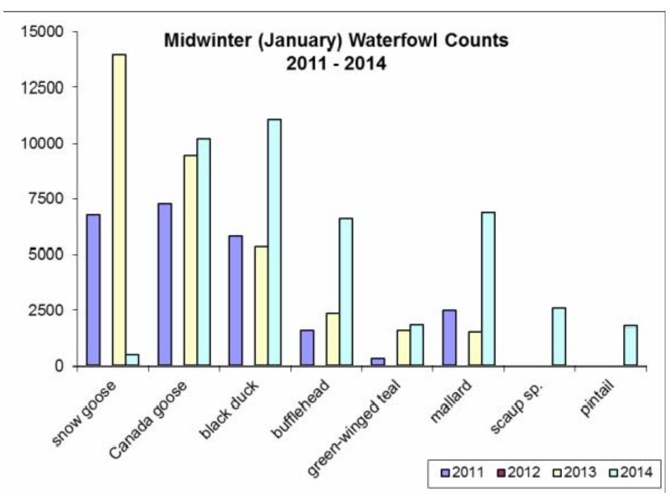
Abundance and diversity data (total counts by species) were compared across the most recent and available three years of the Mid-Winter Waterfowl Survey data (Table 7.8.1), and across the available Christmas Count data from 2008-13 (Table 7.8.2). Differences in methods result in a wider diversity of species identified by the Christmas Count; for example the Mid-Winter Waterfowl Survey does not distinguish between Snow and Ross' Goose, or between species of scaup, and typically does not find extralimital rarities such as Eurasian Wigeon.

There are 44 species of waterfowl and eight species of loons and grebes have been observed overwintering in the Coastal Bays during 2007-13. Sea ducks in particular are attracted to abundant small shellfish resources for food. Dabbling and bay ducks use man-made ponds, including golf course water features, sediment retention ponds, borrow pits, and sewage ponds, in addition to naturally occurring open water habitats for feeding and resting. A large portion of the Atlantic brant population winters in Maryland's Coastal Bays. Historically, this population fed primarily on eelgrass (*Zostera marina*). Longstanding declines and interannual variability in eelgrass abundance since the 1930s have resulted in brant switching to a winter diet dominated by macroalgae and supplemented by saltmarsh cordgrass (Ladin et al., 2014). Several extra-limital species have been observed in the watershed over the years, an indication that the large area of aquatic habitat is attractive to wandering waterbirds. Irruptions, notably red-necked grebes in 2013-14, have occurred as typically northern wintering species are forced south during harsh winters when northern waters are ice-covered.

Table 7.8.1. Coastal Bays Mid-Winter Waterfowl Counts, January 2011-14*

Species	2011	2012	2013	2014
Snow Goose (*Chen caerulescens*)	6800	Data Unavailable	14000	500
Brant (*Branta bernicla*)	1454		1305	280
Canada Goose (*Branta canadensis*)	7275		9447	10225
Tundra Swan (*Cygnus columbianus*)	2		300	117
Gadwall (*Anas strepera*)	105		335	1135
American Wigeon (*Anas americana*)	25		60	200
American Black Duck (*Anas rubripes*)	5811		5329	11038
Mallard (*Anas platyrhynchos*)	2474		1558	6924
Northern Pintail (*Anas acuta*)				1775
Green-winged Teal (*Anas crecca*)	320		1600	1825
Canvasback (*Aythya valisineria*)	500		250	1045
Scaup sp. (*Aythya affinis/marila*)				2605
Surf Scoter (*Melanitta perspicillata*)				265
Bufflehead (*Bucephala clangula*)	1620		2335	6615
Common Goldeneye (*Bucephala albeola*)				15
Hooded Merganser (*Lophodytes cucullatus*)	191		400	62
Red-breasted Merganser (*Mergus serrator*)	60		10	75
Ruddy Duck (*Oxyura jamaicensis*)	300			1020
Total	**26937**		**36929**	**45721**

*reflecting winter populations for 2010-13



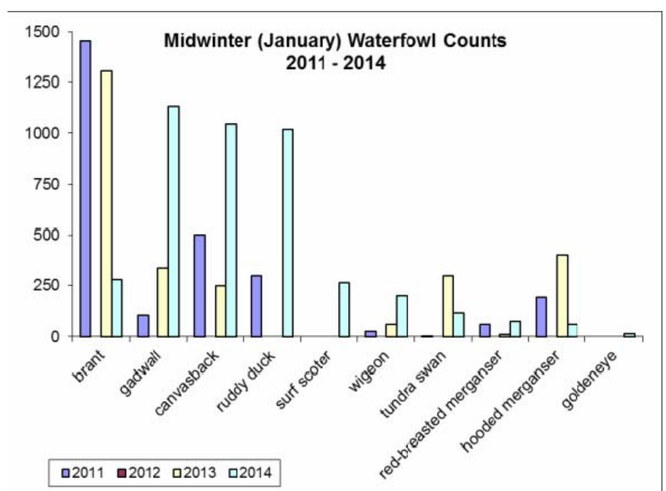


Figure 7.8.3 Midwinter Waterfowl Counts for the Coastal Bays portion of Worcester County (2011-2014)

Table 7.8.2 Waterfowl counts from Ocean City Christmas Bird Counts, 2008-2013. Data exclude Pocomoke North, Pocomoke South, and Berlin territories.

Species	2008	2009	2010	2011	2012	2013
Snow Goose *(Chen caerulescens)*	53331	Data Unavailable	12055	5628	14191	18651
Ross Goose *(Chen rossii)*	0		1	0	1	2
Brant *(Branta bernicla)*	8319		682	2861	5229	438
Canada Goose *(Branta canadensis)*	5626		14193	7572	8269	13510
Tundra Swan *(Cygnus columbianus)*	504		432	250	217	106
Wood Duck *(Aix sponsa)*	5		14	11	4	7
Gadwall *(Anas strepera)*	145		182	315	187	254
Eurasian Wigeon *(Anas penelope)*	0		0	0	0	3
American Wigeon *(Anas americana)*	267		199	489	166	531
American Black Duck *(Anas rubripes)*	822		725	1296	2458	837
Mallard *(Anas platyrhynchos)*	3862		5713	2519	3510	3989
Blue-winged Teal *(Anas discors)*	0		0	0	1	0
Northern Shoveler *(Anas clypeata)*	97		127	51	92	168
Northern Pintail *(Anas acuta)*	85		149	366	55	52
Green-winged Teal *(Anas crecca)*	112		263	1173	362	215
Canvasback *(Aythya valisineria)*	1048		331	28	34	467
Redhead *(Aythya americana)*	37		20	10	3	27
Ring-necked Duck *(Aythya collaris)*	133		116	475	243	1048
Greater Scaup *(Aythya marila)*	420		24	7	13	0
Lesser Scaup *(Aythya affinis)*	497		300	15	107	116
King Eider *(Somateria spectabilis)*	2		0	0	0	0
Common Eider*(Somateria mollissima)*	1		34	72	3	11
Harlequin Duck *(Histrionicus histrionicus)*	2		2	4	3	3
scoter spp. *(Melanitta spp.)*	172		747	483	270	2857
Long-tailed Duck *(Clangula hyemalis)*	33		36	25	57	39
Bufflehead *(Bucephala albeola)*	2268		2512	3153	2367	2231
Common Goldeneye *(Bucephala clangula)*	1		55	3	1	0
Hooded Merganser *(Lophodytes cucullatus)*	313		134	219	339	163
Common Merganser *(Mergus merganser)*	2		0	0	0	0
Red-breasted Merganser *(Mergus serrator)*	169		144	195	203	139
Total	**78273**		**39190**	**27220**	**38385**	**45864**

Migratory Shorebirds

Because of a dearth of scientific survey data for shorebirds in Maryland's Coastal Bays, eBird data were mined for checklists submitted during spring and fall migration (May – October) (Table 7.8.3). Peak counts were identified by date and location for each species. Shorebirds use the Coastal Bays during migration and overwintering, and 38 species have been identified within the watershed between 2007 and 2013. Critical habitats include beaches, tidal flats, salt marshes, and grasslands. The large numbers of sightings and counts of these birds during migration demonstrate the importance of the Coastal Bays habitats.

Table 7.8.3 High counts of migratory shorebirds at sites within the Coastal Bays watershed submitted to eBird, 2007-2013.

Species	Count	Location	Date
American Avocet (*Recurvirostra americana)*	9	Truitts Landing	8-Aug-11
American Golden-Plover (*Pluvialis dominica)*	16	Murray Sod Farm	8-Sep-11
Baird's Sandpiper (*Calidris bairdii)*	1	E.A. Vaughn WMA--North	13-Aug-11
Black-bellied Plover (*Pluvialis squatarola)*	450	Truitts Landing	27-May-13
Black-necked Stilt (*Himantopus mexicanus)*	10	Truitts Landing	16-Apr-11
Buff-breasted Sandpiper (*Tryngites subruficollis)*	10	Murray Sod Farm	6-Sep-12
Greater Yellowlegs (*Tringa melanoleuca)*	106	Truitts Landing	16-Apr-12
Hudsonian Godwit (*Limosa haemastica)*	2	Ocean City--Skimmer Island	1-Sep-12
Least Sandpiper (*Calidris minutilla)*	600	Truitts Landing	8-May-10
Lesser Yellowlegs (*Tringa flavipes)*	230	Truitts Landing	1-May-11
Marbled Godwit (*Limosa fedoa)*	19	Ocean City--Skimmer Island	18-Oct-13
Pectoral Sandpiper (*Calidris melanotos)*	47	Murray Sod Farm	5-Aug-12
Red Knot (*Calidris canutus)*	129	Ocean City--Skimmer Island	1-Jun-12
Red Phalarope (*Phalaropus fulicarius)*	1	Assateague KM 3-4	30-Oct-11
Red-necked Phalarope (*Phalaropus lobatus)*	1	Ocean City Inlet	9-May-13
Sanderling (*Calidris alba)*	8750	Assateague I. NS--OSV Zone	31-Jul-12
Semipalmated Plover (*Charadrius semipamatus)*	550	Truitts Landing	8-May-10
Semipalmated Sandpiper (*Calidris pusilla)*	3000	Truitts Landing	27-May-07
Short-billed Dowitcher (*Limnodromus griseus)*	615	Truitts Landing	6-May-13
Solitary Sandpiper (*Tringa solitaria)*	13	Griffin Rd. Ponds	5-May-11
Spotted Sandpiper (*Actitis macularia)*	12	Truitts Landing	23-Jul-11
Stilt Sandpiper (*Calidris himantopus)*	38	Assateague KM 7.5	7-Aug-11
Upland Sandpiper (*Bartramia longicauda)*	3	Murray Sod Farm	7-Aug-12
Whimbrel (*Numenius phaeopus)*	113	Assateague I. NS--OSV Zone	5-Aug-09
White-rumped Sandpiper (*Calidris fuscicollis)*	30	Truitts Landing	26-May-13
Willet (*Catoptrophorus semipalmatus)*	326	Assateague I. NS--OSV Zone	18-Apr-12
Wilson's Phalarope (*Phalaropus tricolor)*	3	Truitts Landing	17-May-13

<u>Breeding Shorebirds</u>
A portion of the Atlantic Coast population of the federally threatened Piping Plover breeds on Assateague Island, particularly at the northern end where island overwash results in increased forage habitat. (See Chapter 7.7 of this report)

A large portion of the American Oystercatcher population in Maryland depends on the Coastal Bays for breeding habitat. The habitats currently occupied by breeding and wintering American Oystercatchers in Maryland are relatively protected from loss to development and excessive human disturbance. Most oystercatcher pairs breeding on the barrier island of Assateague in Maryland are located on the northern portion of the island that is closed to visitors during the breeding season (Wilke et al., 2007).

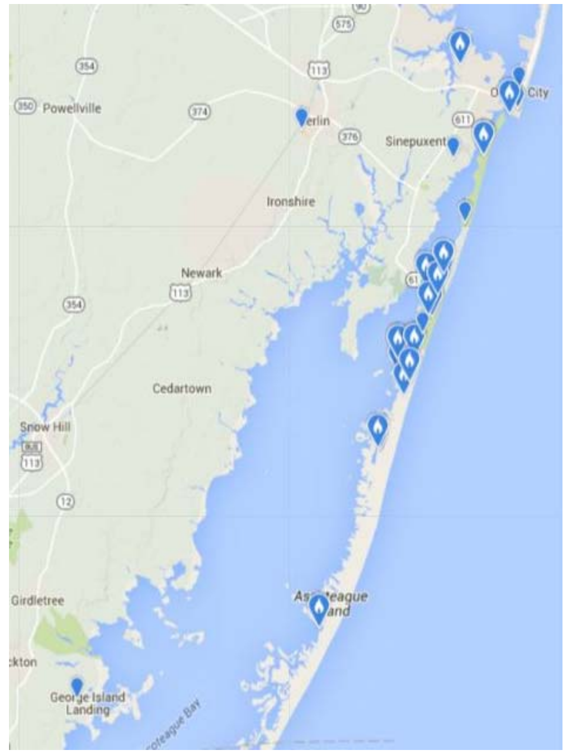


Figure 7.8.4 Coastal eBird sightings of Northern Saw-whet Owl in Maryland **Bays**

<u>Wintering Owls</u>
Northern Saw-whet Owls are regular winter visitors to the Coastal Bays. They migrate from breeding areas in forests of southern Canada, northern US, and Appalachian mountains, as their food resources become scarce during the fall and winter. A banding station has been operated by Project Owlnet on Assateague Island since 1991, and banded >300 Saw-whets between 2007-13. eBird data provide a glimpse of habitat use in the Coastal Bays by these tiny owls (Figure 7.8.4).

Long-eared Owls are rare winter visitors to Maryland. They typically require dense forest habitat undisturbed by human activity. This makes them difficult to detect. During 2008 and 2013, wintering long-eared owls were found in two areas of the southern Coastal Bays watershed (Figure 7.8.5).

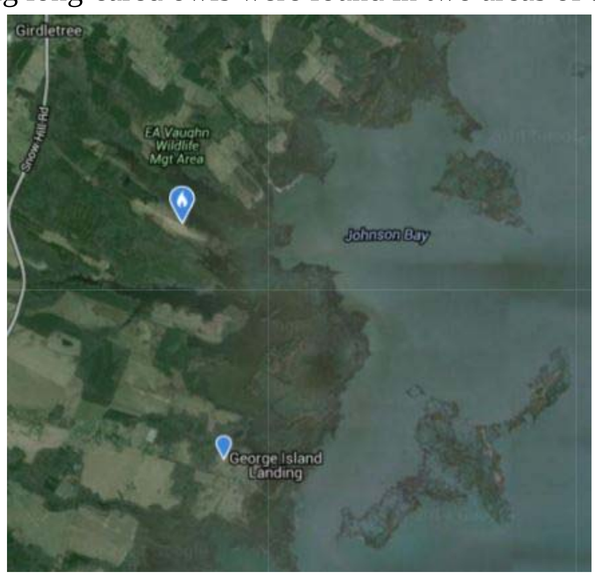
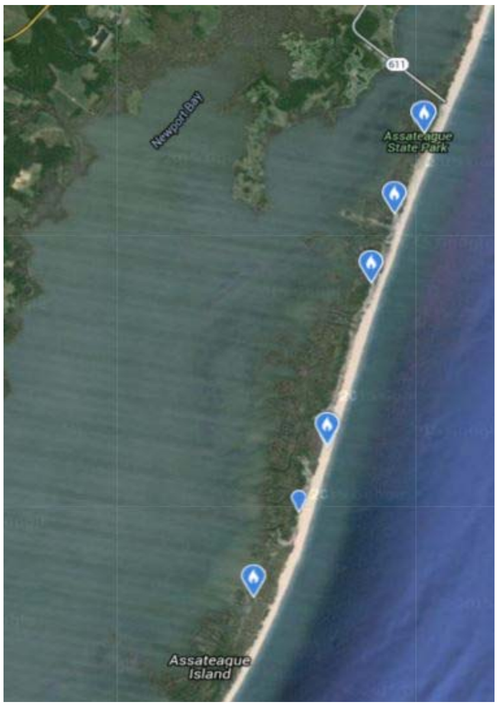


Figure 7.8.5 eBird sightings of Long-eared Owl in Maryland Coastal Bays 2007-13.

Snowy Owls wandering from their normal range during the winter find familiar tundra-like landscapes in the Coastal Bays, particularly on Assateague Island. Beginning in November 2008, eBird checklists located an immature female on Assateague for at least 68 days (Figure 7.8.6a). Extraordinary breeding success during 2013 led to many juvenile Snowy Owls expanding their range into coastal Maryland to find suitable overwintering habitat (Figure 7.8.6b). Scientists and managers scrambled to capture and tag a significant number of these birds with GPS-GSM transmitters, including two released on Assateague Island. Tracking data provided by Project Snowstorm shows the extensive use of the southern Coastal Bays for foraging and resting by one owl over the course of 20 days (Figure 7.8.7). (http://www.projectsnowstorm.org/maps-2014-15/delaware/)



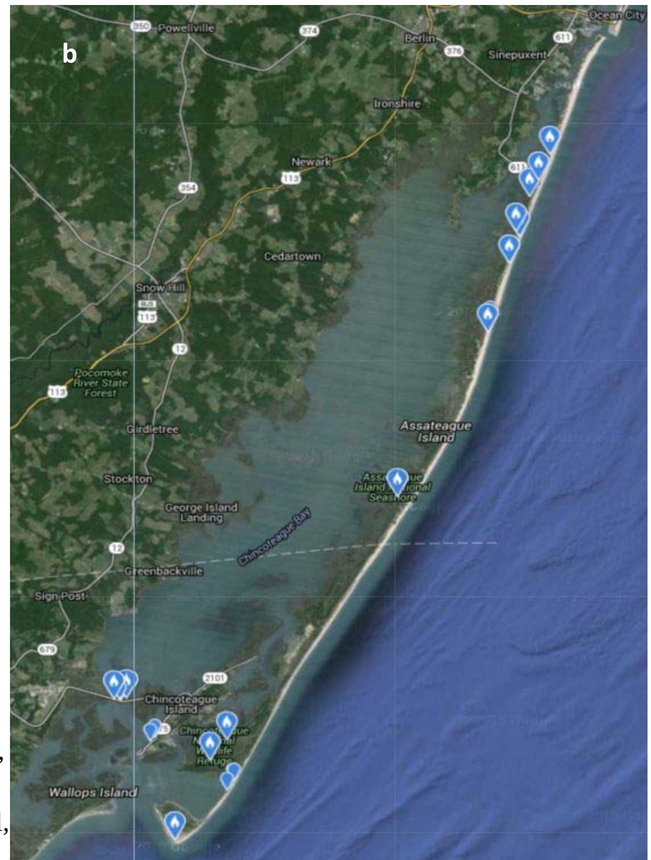


Figure 7.8.6 a) eBird sightings of Snowy Owl, November 2008 – February 2009, Maryland Coastal Bays. b) eBird sightings of Snowy Owl, winter 2013. Maryland Coastal Bays.

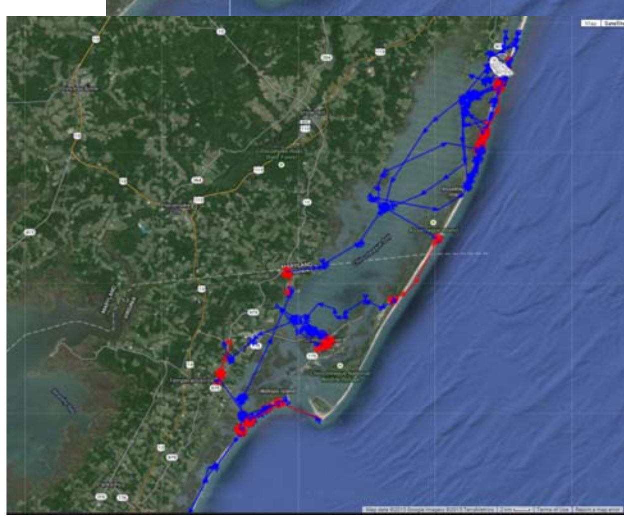


Figure 7.8.7 GPS track of Snowy Owl Delaware, December 11-31, 2014

Summary
The Coastal Bays provide critical foraging resources and habitats for breeding, wintering, and migration resting areas for birds. The confluence of land and water, plus the diversity of habitats within Maryland's Coastal Bays results in a wide diversity of bird species found within the watershed. Worcester County has the highest diversity of birds among all counties of Maryland.

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Chapter 8.1

Coastal Bays Ecosystem Health Index: Bringing it all together

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Abstract
Estuarine health indicators comprised of water quality, living resources and habitat features were used to compare the different bay segments within the Maryland Coastal Bays. The selected estuarine health indicators are responsive to human activities and were measured throughout the Maryland Coastal Bays. Overall bay health ranked Sinepuxent best followed closely by Chincoteague Bay and St. Martin River worst. Assawoman, Isle of Wight and Newport bays were all ranked similarly in a fair to poor status. Continued nutrient reduction and habitat preservation/restoration are needed in all subwatersheds except Sinepuxent.

Introduction
The preceding chapters described the environmental status and trends of the many ecosystem indicators monitored in the Maryland Coastal Bays to provide a tracking point for how the bays are faring. While many of these indicators showed improvements throughout the bays, such as water quality, others had definitive downward trends, such as seagrass acreage. Furthermore, status and trends in several ecosystem elements varied, sometimes widely, between bay segments. Likewise, if tributaries and the open water bays are separated and compared, marked differences in indicator values, especially water quality, become apparent.

The purpose of this document is to provide a comprehensive assessment of ecosystem health for use in driving policy decisions. The information on the status of the various indicators contained in each chapter are important individually, especially to stakeholders interested in one or a few indicators, those who are responsible for making decisions affecting the ecosystem often request more comprehensive answers. To this end, an estuarine health index was developed based on the results of this report and a summary of overall ecosystem health.

Estuarine health indicators comprised of water quality, living resources, and habitat features were used to compare the different bay segments within the Maryland Coastal Bays. The selected estuarine health indicators are responsive to human activities and were measured throughout the Maryland Coastal Bays. Two water quality indicators (water quality index and macroalgae), two living resources indicators (benthic index and hard clam abundance), and two habitat indicators (seagrass area and wetland area) were used to rank the estuarine health in each embayment. Though the index covers a wide variety of indicators used in the preceding report, its coverage is not exhaustive. For instance, no stream or fisheries indicators were used to create the index. Furthermore, all of the indicators used were weighted equally in the analysis.

Analysis

For each of the six indicators listed above, average values over each of the Coastal Bays segments were calculated. Each indicator was scored based on the data in the preceding report as follows:

Water quality index

The water quality index was a within-segment average of the water quality index values calculated for each Coastal Bays fixed station. This index was calculated from three-year median values for total nitrogen and phosphorus, chlorophyll *a* concentration, and dissolved oxygen concentration. Please see Chapter 4.4 for a detailed explanation of how the water quality index was calculated as well as values for each station.

Macroalgae

Maximum total macroalgal biomass per square meter (g/m^2) within each segment over the period 1999 through 2013 was used. While raw macroalgal biomass was not reported in this document, the values used for this indicator were the same as those used to develop Figure 5.4.1 (see Chapter 5.4).

Benthic index

The within-segment mean Mid-Atlantic Integrated Assessment (MAIA) benthic index score (2010) was used (see Chapter 7.4).

Hard clams

The average of the number of clams per station within each segment for 2013 was used (see Chapter 7.3, especially Figure 7.3.2).

Seagrass area

The total seagrass acreage within each segment was used, based on the 2013 survey data (see Chapter 5.1). These values were then converted to a percentage of goal attainment for that subwatershed.

Wetland area

Raw within-segment National Wetland Inventory acreages from the 1988 through 1989 survey were used. These values were then converted to a percentage of the total watershed land acreage. Since Isle of Wight Bay and the St. Martin River were considered one segment for this analysis, the scaled value for the combination was used for each in the final analysis.

Results

Within-segment means served as raw index values for each segment (Table 8.1.1). Raw values were converted to scaled values by setting the lowest score among the segments to zero and the highest to one. Those scores falling between zero (worst) and one (best) were scaled accordingly (Table 8.1.2). The set of scaled values was then averaged within segment, resulting in a final estuarine health index value for each segment (Table 8.1.2).

Table 8.1.1 Raw values for each indicator by segment. Indicators are divided into water quality (blue), living resources (yellow), and habitat (green) categories.

Indicator / Segment	WQI[1]	Macroalgae[2]	Benthic index[3]	Hard clams[4]	Seagrass area[5]	Wetland area[6]
Assawoman Bay	0.33	718.3	3.25	0.28	35.14	45
Isle of Wight Bay	0.44	545.2	2.88	0.73	22.6	44
St. Martin River	0.11	134.1	1.83	0.06	3.96	44
Sinepuxent Bay	0.70	49.6	5	0.33	62.06	61
Newport Bay	0.34	99.2	2.25	0.1	16.75	25
Chincoteague Bay	0.56	74.8	3.89	0.18	45.62	62

[1]Water quality index ranges from 0 (no reference criteria met) to 1 (all reference criteria met). [2]Grams/m^2. [3]Ranges from 1(poor) to 5(good). [4]Clams/m^2. [5]Percent of segment goal met. [6]Percent of watershed.

Table 8.1.2 Scaled values for each indicator by segment, based on raw values in Table 8.1.1 (zero values are the worst ranking and one is the best condition). Final index values are also shown. Indicators are divided into water quality (blue), living resources (yellow), and habitat (green) categories.

Indicator / Segment	WQI[1]	Macroalgae	Benthic index	Hard clams	Seagrass area	Wetland area	**Estuarine Health Index**
Assawoman Bay	0.4	0.0	0.4	0.3	0.5	0.6	**0.4**
Isle of Wight Bay	0.6	0.3	0.3	1.0	0.3	0.0	**0.4**
St. Martin River	0.0	0.9	0.0	0.0	0.0	0.0	**0.1**
Sinepuxent Bay	1.0	1.0	1.0	0.4	1.0	1.0	**0.9**
Newport Bay	0.4	0.9	0.1	0.1	0.2	0.2	**0.3**
Chincoteague Bay	0.8	1.0	0.6	0.2	0.7	0.6	**0.7**

[1]Water quality index.

Discussion

Final rankings, based on average scaled values, were, from best to worst: Sinepuxent Bay, Chincoteague Bay, Assawoman Bay/ Isle of Wight Bay, Newport Bay and St. Martin River (Table 8.1.3). These segment rankings are all relevant to each other; that is, no reference estuaries were used to base ranking. Generally, the pattern of rankings reflects those predicted by most of the indicators used in the preceding document, with tributary dominated subwatershed demonstrating lower indices than open bay segments and southern bays scoring better than northern bays. These indices, based on raw values, are summarized in Table 8.1.3, which should be referenced throughout the rest of this discussion.

Sinepuxent Bay had the highest ranking of 0.9 because it scored the highest or near the highest for all indicators. This highest ranking reflects this segment's small, relatively undeveloped watershed. Sinepuxent Bay is also well-flushed, due to its proximity to the Ocean City Inlet.

Chincoteague Bay ranked second, at 0.7, largely due to macroalgae. High seagrass area also contributed to the relative health of this largest segment of the Coastal Bays. Like Sinepuxent Bay, Chincoteague Bay is relatively undeveloped, due to its proximity to the protected Assateague Island National Seashore, but has a much larger watershed.

Assawoman and Isle of Wight segments tied for third both with a rank of 0.4. Assawoman Bay had a low water quality index (identical to Newport Bay), due to high nutrient and chlorophyll *a* levels, as well as very low seagrass area drove this ranking. Grey's and Roy's creeks, and the ditch connecting Assawoman Bay to Little Assawoman Bay in Delaware contributed the most to the low water quality index value. Assawoman Bay was saved from a lower ranking due mainly to mid-range habitat indicators (wetlands and seagrass coverage).

Isle of Wight Bay demonstrated the highest hard clam densities and reasonable water quality, but low values in both habitat indicators. Despite being downstream of heavily eutrophic St. Martin River and containing several nutrient-impacted waterways (Turville, Herring, and Manklin Creeks), water quality was mid-range for this segment. This could be due to flushing from the Ocean City Inlet. Next to the St. Martin River, Isle of Wight Bay has the most developed watershed in the Coastal Bays. This heavy development has been implicated in the low values of habitat indicators.

Newport Bay ranked fifth among the Coastal Bays' segments due to poor water quality, low living resources and low habitat indicators. Newport Bay suffers from chronically high phytoplankton concentrations (as evidenced by chlorophyll *a* values) reduced hard clam densities, and very little seagrass coverage. Newport Bay is somewhat sheltered, and thus not well flushed. Another contributor to these poor indicator values may be increasing development in the upper reaches of the watershed (second most populated subwatershed).

Ranking last, the St. Martin River had the lowest index values for all indicators except macroalgae. This river had the highest phytoplankton and phosphorus concentrations, as well as the lowest dissolved oxygen concentrations (see breakout in Table 8.1.3). All three living resources indicators ranked the lowest in this river, and seagrass and wetlands were nearly non-existent. A combination of poor flushing and heavy nutrient loading from both agriculture and development probably contribute to the decline of the St. Martin River.

Overall, this break-down of the Coastal Bays into segments and the development of this index provides a thumbnail sketch of how the Coastal Bays fare ecologically. The northern bays are doing worse, in general, than the southern bays. Such an index provides a concise report that is easily accessible by stakeholders and interested citizens alike. Those responsible for managing the resources in a certain segment or the bays as a whole will hopefully find this useful, as will citizens living in the individual watersheds. This index also provides a means to summarize a comprehensive report that is based on reams of data and associated analyses.

However, this approach has its drawbacks. First, not all of the data contained in the full report lent itself to use in the index. As a result, some potentially informative indicators were left out altogether. For example, the coastal bays fishery program data was not set up to give information at the sub-watershed scale but to determine overall stock changes.. This is partially to do with the fact that the index was developed *a posteriori*, but since the entire report is a compilation of many different studies and long term monitoring programs this was unavoidable.

Furthermore, certain indicators had to be dropped compared to previous assessments (Dennison et al 2009 and Carruthers et al 2004) due to no updated data for sediment toxicity, shorelines, or wetlands. To keep a balanced approach between the three categories (water quality, habitat and living resources) one indicator was dropped from each category (brown Tide, sediment toxicity and shorelines). Updating the date for each of the missing data sets or determining new indicators in the categories would be beneficial to the overall ecological health assessment.

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Table 8.1.3 Estuarine health index results,

2011–2013 ESTUARINE HEALTH INDEX		Sinepuxent Bay	Chincoteague Bay	Isle of Wight Bay	Assawoman Bay	Newport Bay	St Martin River
WATER QUALITY	Water quality index	10.0	7.6	5.6	3.7	3.9	0.0
	Macroalgae	10.0	9.6	2.6	0.0	9.3	8.7
LIVING RESOURCES	Benthic index	10.0	6.5	3.3	4.5	1.3	0.0
	Hard clams	4.0	2.0	10.0	3.0	1.0	0.0
HABITAT	Seagrass area	10.0	7.2	3.2	5.4	2.2	0.0
	Wetland area	10.0	6.4	0.0	6.4	1.6	0.0
ESTUARINE HEALTH INDEX		**9.0**	**6.6**	**4.1**	**3.8**	**3.2**	**1.5**

This table shows the 2011–2013 Estuarine Health Index for each of the Coastal Bays. Each indicator is scored from 0–10, based on how close it is to achieving the goal for that indicator, where a score of 0 = 0% attainment and a score of 10 = 100% attainment.