Maryland's Coastal Bays

Ecosystem Health Assessment

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DEPARTMENT OF
NATURAL RESOURCES

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Executive Summary

Maryland's Coastal Bays, the shallow lagoons nestled behind Ocean City and Assateague Island, comprise a complex ecosystem. These estuarine bays, at the interface between fresh and saltwater, provide habitat for a wide range of aquatic life. But like many coastal systems, they face threats from intense development, nutrients, sediments, and other stresses associated with human activities. This report documents the most up-to-date status of water quality and living resources in the Coastal Bays and highlights management steps being taken to preserve them.

Overall, the Coastal Bays reveal differences in water quality with generally degraded conditions in or close to tributaries and good conditions in more open, well-flushed bay regions. Showing the strain of nutrient enrichment, the Coastal Bays exhibit high nitrate levels in freshwater reaches of streams, chronic brown tide blooms, macroalgae blooms, and other harmful algal blooms associated with excess nutrients. Although large increases in seagrasses took place during the 1990's, these increases have leveled off during the past three years.

In terms of aquatic species health and water quality conditions, the bays fare as follows from best to worst: southern Chincoteague Bay, Sinepuxent Bay, northern Chincoteague Bay, Isle of Wight Bay, Assawoman Bay, Newport Bay, and St. Martins River. The bays show a tendency toward poorer water quality from south to north.

Like water quality, the status of Coastal Bays living resources is mixed. While the bays still support diverse and abundant populations of fish and shellfish, human activities are affecting their numbers. Forage fish, the major prey item for game fish, have been in steady decline since the 1980s, and reports of fish kills, usually the result of low oxygen levels, are increasing. Hard clam densities are lower than historic levels but generally stable over the past 10 years. Blue crab populations are fluctuating but do not appear to be in decline, despite a relatively new parasite causing summer mortality. Oysters, which were historically abundant in the Coastal Bays, now cling to small, relict populations. Bay scallops, however, have recently returned to the bays after being absent for many decades, although numbers are low.

In response to these changes, dozens of organizations, groups, and agency partners have implemented a wide range of management activities. Fishery management plans, nutrient reduction goals, shoreline restoration, and sewage upgrades along with several hundred other initiatives are serving and will serve to improve the condition of the Coastal Bays. In addition, ongoing monitoring programs now track status and trends in this coastal ecosystem, and new research is aiding scientists in their quest for solutions.

This report presents a technical overview of the current state of the Coastal Bays and should help serve as a guide for preserving this ecosystem. However, human population is expected to climb steadily in the Coastal Bays watershed and the associated impacts of this growth will present future challenges to the health of the bays. Maintaining active

and vigorous environmental monitoring and management programs will be essential to preserve this fragile estuary.

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General Introduction

Gaining an understanding of the health of an ecosystem requires the appropriate monitoring and analysis of the resulting data. Of course, such a monitoring program should be based on sound scientific research into the factors that affect the health of the ecosystem at hand. The Maryland Coastal Bays are lagoonal estuaries: coastal areas fringed by barrier islands or reefs where freshwater mixes with saltwater. While most ecosystem characteristics and processes are common to all coastal lagoons, all, including the Maryland Coastal Bays, are unique in some way. Therefore, before delving into the current health status and trends of this ecosystem, an introduction to its function and the monitoring programs that provide the data for its assessment is appropriate. The following chapters detail the monitoring programs in the Coastal Bays as well as provide a characterization of this coastal lagoon ecosystem.

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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 US 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, sandy sediments and limited freshwater flow. 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 Coastal Bays and provide 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 (Maryland Coastal Bays Program 1999a). **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 Coastal Bays' health.** It contains many of the traditional measures for assessing aquatic ecosystem health.

The Maryland Coastal Bays Eutrophication Monitoring Plan, also known as the Aquatic Ecosystem Health Monitoring Plan, was developed to help determine the effectiveness of management actions taken as part of the CCMP (Maryland Coastal Bays Program 1999b). Actions in the Coastal Bays 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 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**. 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 (Maryland Coastal Bays Program 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, inform environmental policy decisions, and evaluate 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 stock 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 (Table 1.1.1). Thresholds were approved by the STAC. DNR scientists have worked with the MCBP, the University of Maryland, and other researchers to evaluate the Coastal Bays monitoring data collected since 2001.

The Maryland Coastal Bays Ecosystem Health Assessment is intended to provide comprehensive monitoring coverage over a three-year period. This ecosystem health assessment is intended to support other publications, such as the MCBP Progress Report. 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. 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. This assessment will also provide a reference for the University of Maryland Center for Environmental Science Integration and Application Network (IAN) report card. The IAN report card will be produced later this year, providing a snapshot of Coastal Bays water quality based on intensive sampling over a few days.

For this report, the Coastal Bays 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 indicators and thresholds

Aquatic Ecosystem Component	Indicator	Threshold	Monitoring Frequency
Stream Health	Stream nitrate	Less than 1 mg/L	Highly varied
	Stream benthic index1	Less than or equal to 2.8	Annually
	Stream benthic 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 µg/L to prevent low dissolved oxygen; No more than 50 µg/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
Sediment Quality	Excess Organic Carbon	Less than or equal to 1%	Periodically
	Mean Apparent Effects Threshold	None	Calculated from sediment contaminant data (2000-2003)
	Ambient Toxicity	Significant difference from uncontaminated sediment	Annually 2000 - 2003
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	Direct wetland losses from permitted activities tracked.
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
	Benthic organisms	Federally-mandated index values	Annually 2000 - 2003
	Exotic species	Presence	Survey 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 in the Coastal Bays, 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	**Indicator**	**Monitoring group***
Stream Health	Stream nitrate	DNR- WRS; USGS; DNR- MANTA
	Stream benthic index1 Stream benthic index2	DNR- MANTA DNR- MBSS
	Freshwater fish index	DNR- MBSS
Water Quality	Total nitrogen	ASIS DNR – TEA
	Total phosphorus	ASIS DNR – TEA
	Chlorophyll *a*	ASIS DNR – TEA MCBP UMCES
	Dissolved oxygen	ASIS DNR – TEA UMCES
	Water quality index	UMCES
Sediment Quality	Excess organic carbon	DNR-MGS
	Mean apparent effects threshold	DNR- MGS
	Ambient toxicity	DNR - TEA
Harmful Algae	Harmful algae blooms	DNR - TEA
Habitat	Seagrass	VIMS
	Macroalgae	DNR - TEA
	Shoreline	DNR-MGS
	Wetlands	DNR-WRS MDE USACE
Living Resources	Phytoplankton	DNR-MANTA
	Fish	DNR – FISH
	Fishkills	MDE
	Shellfish (clams, scallops, oysters)	DNR –FISH
	Blue crabs and horseshoe crabs	DNR – FISH
	Benthic index	DNR - TEA
	Exotic species	UDCMS

* 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.

The Maryland Department of Natural Resources (DNR), National Park Service at Assateague Island (ASIS), and the MCBP volunteers all routinely monitor water quality (Maryland Coastal Bays Program 1999a). The University of Maryland Center for Environmental Science (UMCES) provides expertise in water quality mapping. The United States Geological Survey (USGS) analyzes ground water inputs to the estuary (Dillow et al. 2002). Maryland DNR also monitors stream health, sediment quality, and harmful algae blooms. Habitat monitoring is conducted by the Virginia Institute of Marine Science through annual aerial surveys of seagrass bed distribution (Virginia Institute of Marine Science 2003), while macroalgae abundance and distribution (McGinty et al. 2002) and shoreline change (Maryland Geological Survey 2004) is tracked by DNR. The Maryland Department of the Environment (MDE) teams with DNR to collect data on wetlands (Maryland Department of the Environment 2004a). Fish, blue crabs, shellfish, and benthic communities are surveyed by DNR (Maryland Coastal Bays Program 1999a) while fish kills are monitored by MDE (Maryland Department of the Environment 2004b). The University of Delaware has surveyed exotic species abundances and their presence is recorded during MD DNR fish surveys.

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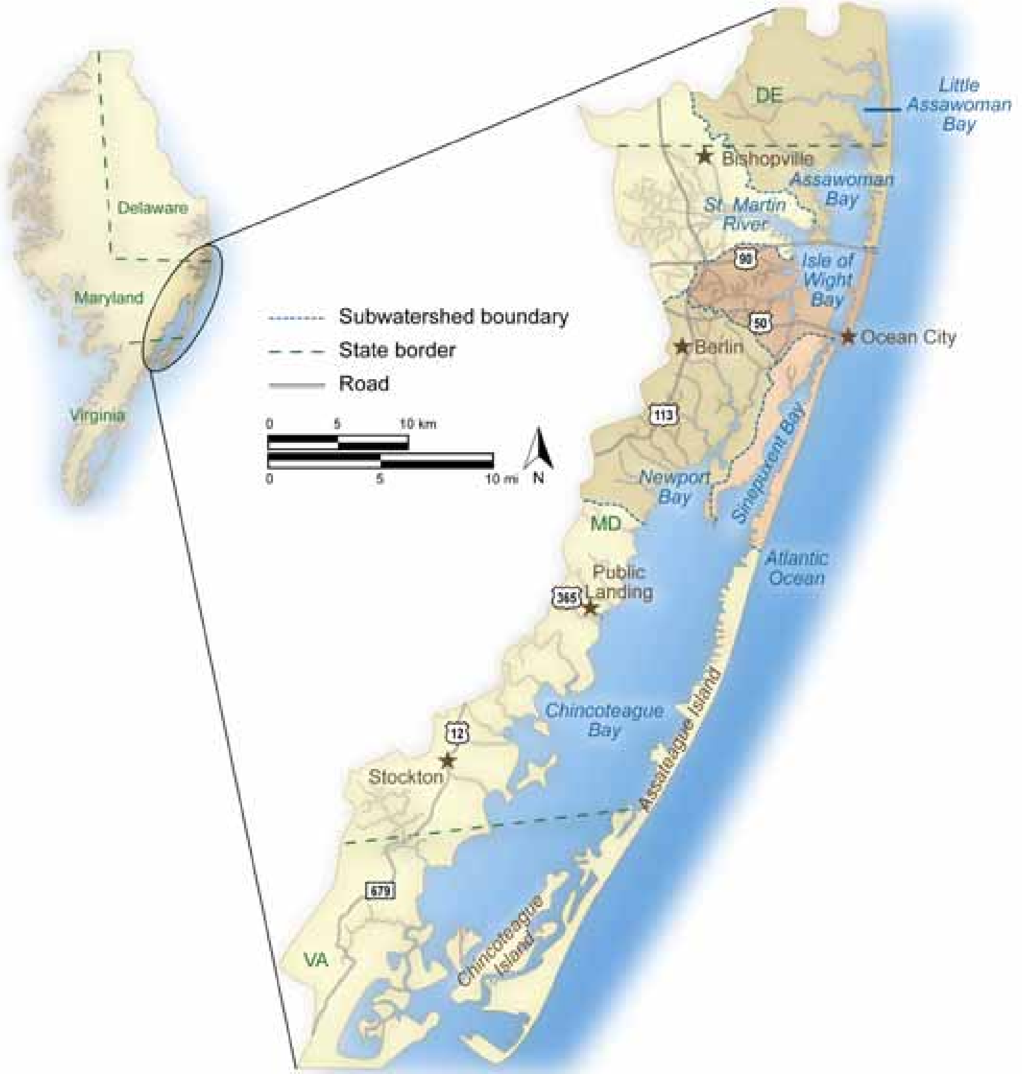

Figure 1.1.1: General location of Maryland's Coastal Bays along the east coast of the Del-Mar-Va peninsula, United States. The watershed area of each of the Coastal Bays segments is also shown.

Chapter 1.2

The Maryland Coastal Bays ecosystem

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Introduction

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 Ocean is limited to two inlets, one dividing Fenwick and Assateague Islands and the second in Virginia south of Chincoteague Island. 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 Bay, Delaware Bay, Raritan Bay, Narragansett Bay, San Francisco Bay, and Puget Sound.

Influence of the ocean: barrier islands

Barrier islands are rocky, sandy islands and beaches, spits, dunes, eroding headlands, and wetlands located along the Atlantic and gulf coasts. There are 282 barrier islands along the U.S. coastline (Lins 1980). Coastal barriers provide a physical barrier separating bays from ocean yet still allow some mixing with the sea. The beaches and the wildlife resources of these islands attract thousands of tourists and millions of tourist 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 (Figure 1.2.2). 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 marshlands 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 storm 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 also push sand towards the mainland. 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 are transported to the south side. Where man puts hardened structures like jetties or groins in place, the process is interrupted and 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; Figure 1.2.2). 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 (rate of 35 feet per year) has shifted Assateague Island almost one-half mile (0.8 km) inland (USACE 1998). As a result, the Ocean City Inlet is among the best-studied and understood inlets in the world, courtesy of Federal, state and local government tax dollars funding the USACE. Nevertheless, human interventions have permanently altered the barrier island profile (Freudenrich 2004)

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 exchange with the 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 (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 indicator varies from flushing time due to water column kinetics. Processes such as algal uptake and settling of phytoplankton tend to decrease residence time while nutrient recycling increases residence time. Intense benthic – pelagic coupling, which is common in systems such as these, increases the impact of contaminants, such as nutrients, entering the bays.

Nutrient loading

Since point sources (three industrial and four wastewater treatment plants) are heavily regulated in the Coastal Bays, their estimated contribution of nutrients is small (less than five percent of total nutrients) (Boynton et al. 1993). Nutrient inputs to the Coastal Bays are dominated by non-point sources (e.g., surface runoff, groundwater, atmospheric deposition, 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-half to two-thirds 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. The coastal bays are believed to be generally nitrogen limited rather than phosphorus limited (Boynton et al. 1996)

Table 1.2.1 Key physical characteristics of each bay segment (U=unknown).

Bay Segment	Watershed 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 Bay - MD	24.7	1.20	20.9	1.18	27.0	0.91	21.2
Isle of Wight Bay	51.8	1.22	21.1	2.45	22.85	2.27	9.45
St. Martin River	95.5	0.67	8.40	11.4	5.63	16.96	12
Sinepuxent Bay	26.7	0.67	24.1	1.1	16.5	1.62	U
Newport Bay	113	1.22	15.9	7.1	19.4	5.82	U
Chincoteague Bay (MD)	141	1.22	189	0.75	231	0.61	63
Chincoteague Bay (VA)	174.5	U	188	0.93	143.5	1.22	U
Coastal Bays System MD	452	U	282	1.6	322	1.40	U
Chesapeake	165,759	6.4	18,130	9.1	68,137.	2.4	U

Bay					4		

Anthropogenic nutrient inputs to estuaries are often confounded by significant natural source (e.g., wildlife) inputs and complex delivery systems. Understanding the hydrology and the hydrological functions of a system, therefore, is also vital to assessing nutrient impacts on a system. Determinations must be made on where and how the nutrients are delivered, as well as the time, conditions, and magnitude of the delivery.

Bathymetry and 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 (Table 1.2.1). 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 mud along the western shoreline (Boynton et al. 1993; Figure 1.2.3). The average textural composition of the bay bottom sediments is 60% sand, 27% silt and 13% clay (Wells et al. 1997). The average percent organic carbon by dry weight at 0.39 percent (extremely low for an estuarine system). The major source of sedimentation to Chincoteague Bay is storm overwash events, shore erosion 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 (Table 1.2.1). 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 1.2.3). Total carbon averaged 1.86 percent 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 (Boynton et al.1993; Table 1.2.1). This bay has the shallowest average depth (0.7 m), despite depths around the Ocean City Inlet reaching 7.8 m. The federal government now maintains the inlet and the Ocean City harbor channel. Bottom sediments are fairly course, consisting mostly of sand and, to a lesser degree, silt (Wells et al. 1996; 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) as well as shore erosion. The contribution of fine-grained material from shore erosion is approximately eight times that introduced by streams (Bartberger 1976).

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) (Boynton et al. 1993; Table 1.2.1). The federal government now maintains the inlet as well as a channel up the Isle of Wight Bay through periodic dredging, though the inlet throat depth is primarily maintained by scour from tidal currents. Sandier sediment is found along the eastern portions of Isle of Wight Bay, due to overwash and erosion from Fenwick Island. However, since the mid-1970s, development along Fenwick Island has essentially prevented overwash. 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 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. The average bottom sediment composition for Isle of Wight and Assawoman Bay combined (including the St. Martin River) is 54% sand, 28% silt, and 18% clay (Figure 1.2.3). Total carbon content averages 2.08%, with carbon content reflecting a combination of both terrigenous and planktonic sources (Wells et al. 1994).

Comparison to other Estuaries

Nutrient enrichment in this shallow, poorly flushed coastal bay system is a problem. Progressive eutrophication threatens the long-term health and function of the estuary. Increasing anthropogenic eutrophication and associated environmental and biotic impacts in this and other East Coast estuaries appear to be representative of what is happening in many coastal bay systems worldwide (Figure 1.2.4).

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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 freshwater.

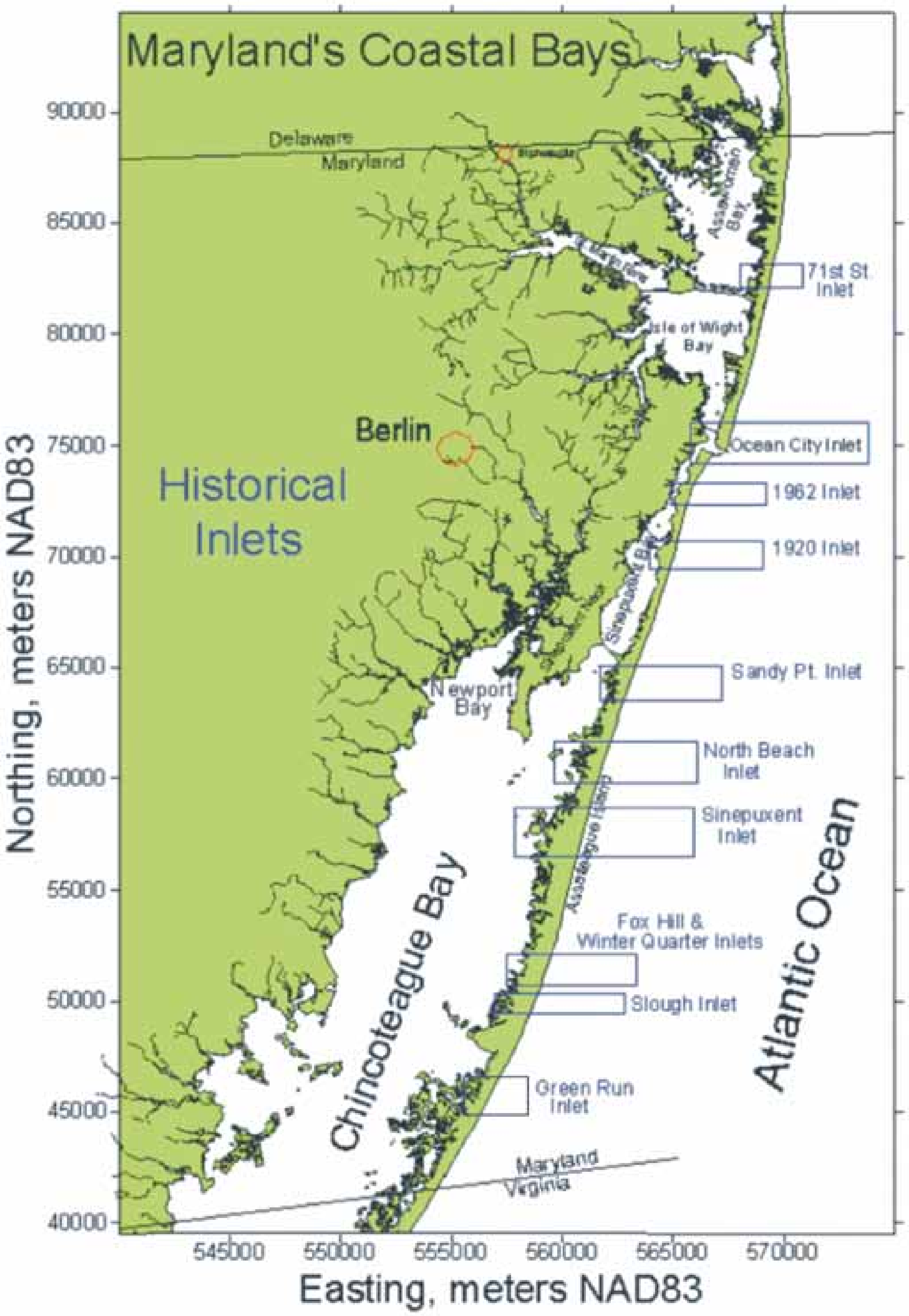


Figure 1.2.2: Historic inlets of the Maryland Coastal Bays, including the current Ocean City Inlet opened in 1933 (see chapter 2.1 for details on time periods for inlets).

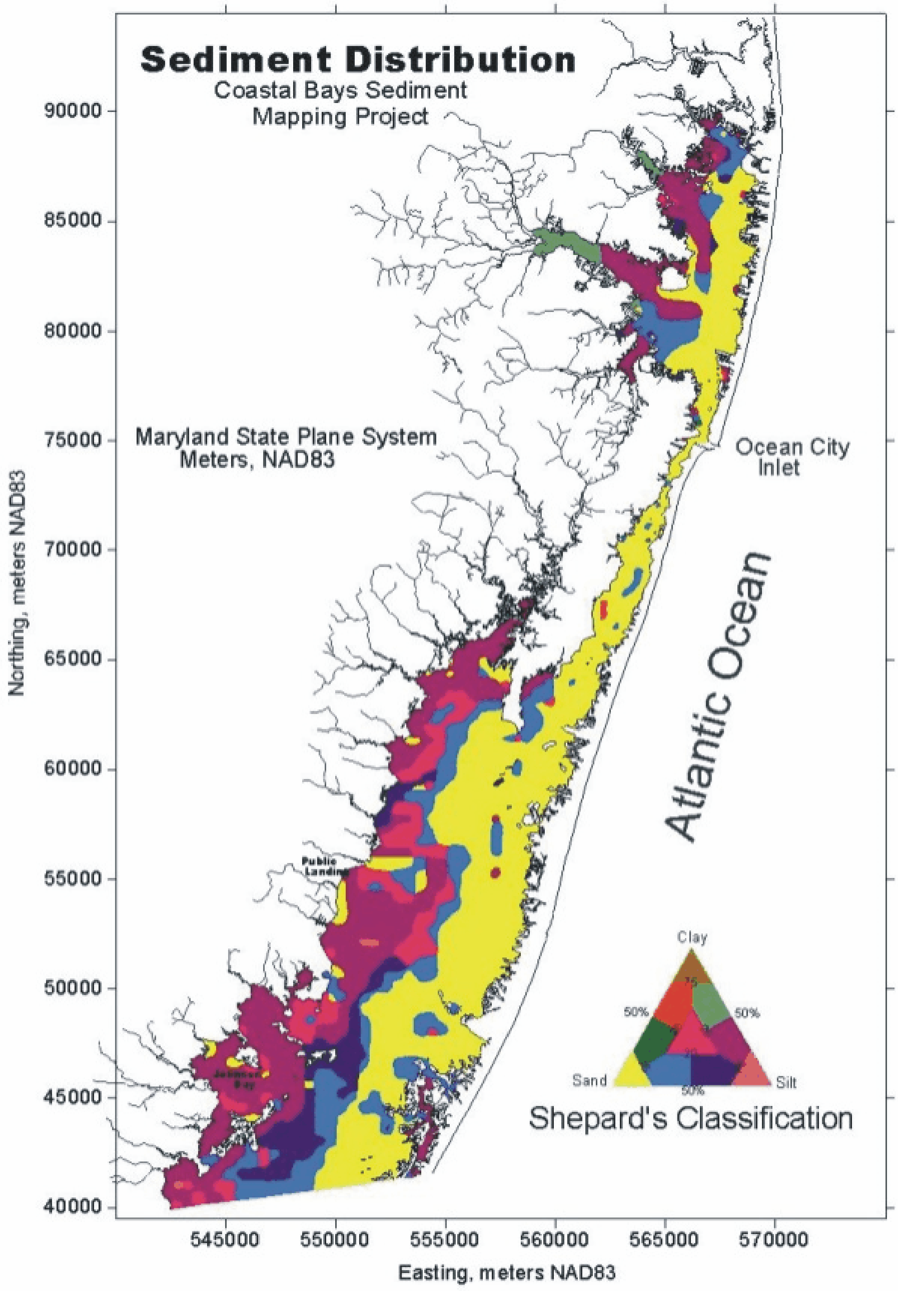
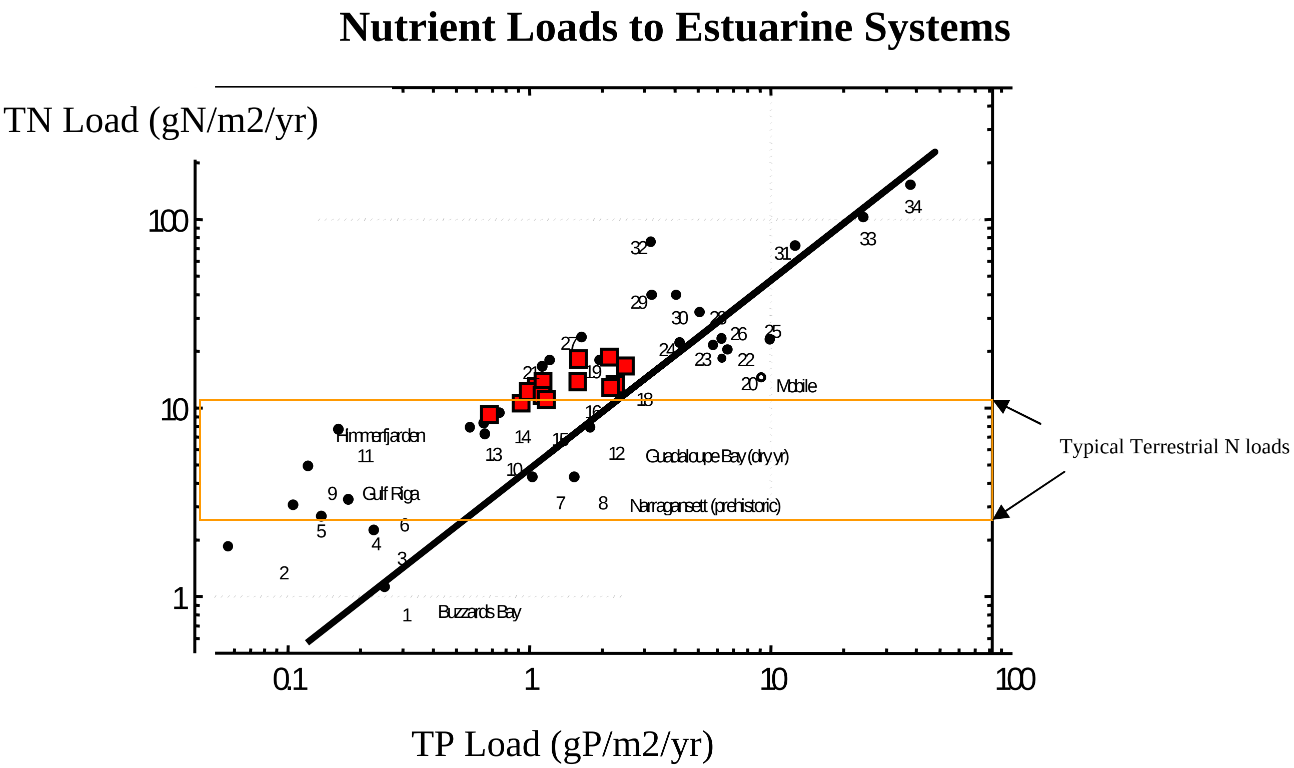


Figure 1.2.3: Sediment distribution in Coastal Bays shallow sediments. The Shepard's classification legend, based on Shepard (1954), shows the relative percentages of sand, silt, and clay in the sediments.



Nutrient Loads to Estuarine Systems

Figure 1.2.4: Scatter diagram showing annual total nitrogen (TN) and total phosphorus (TP) loading rates to a sampling of estuarine and coastal systems. The square symbols represent loads for the Patuxent River estuary for the years 1985-1997. The bold line represents the Redfield Ratio (weight basis). System identification and data sources are as follows: 1 Buzzards Bay, MA (NOAA/EPA 1989); 2 Sinepuxent Bay, MD (Boynton et al. 1992, 1996); 3 and 7 Kaneohe Bay HI pre and post-diversion (Smith et al. 1981); 4 Isle of Wight Bay, MD (Boynton et al. 1992, 1996); 5 Baltic Sea (Nixon et al. 1996); 6 Chincoteague Bay, MD (Boynton et al. 1992, 1996); 8 and 24 prehistoric and current Narragansett Bay, RI (Nixon et al. 1996, Nixon 1997); 9 Gulf of Riga (Yurkovskis et al. 1993); 10 Albemarle Sound, NC (Nixon et al. 1986b); 11 Himmerfjarden, Sweden (Engqvist 1996); 12 and 26 Guadaloupe Bay, TX dry and wet years (Nixon et al. 1996); 13 Buttermilk Bay, MA (Valiela and Costa 1988); 14 Moreton Bay, Australia (Eyre and McKee 2002); 15 Seto Inland Sea, Japan (Nixon et al. 1986b); 16 Taylorville Ck, MD (Boynton et al. 1992, 1996); 18 Newport Bay, MD (Boynton et al. 1992, 1996); 19 N. Adriatic Sea (Degobbis and Gilmartin 1990); 20 Mobile Bay, AL (NOAA/EPA 1989); 21 Chesapeake Bay, MD (Boynton et al. 1995); 22 MERL(1x), Univ RI (Nixon et al. 1986); 23 Delaware Bay, DE (Nixon et al. 1996); 25 N. San Francisco Bay, CA (Hager and Schemel 1992); 27 Potomac River estuary, MD (Boynton et al. 1995); 28 St Martins River, MD (Boynton et al. 1992, 1996); 29 Apalachicola Bay, FL (NOAA/EPA 1989, Mortazavi et al. 2000); 30 Patapsco River, MD (Stammerjohn et al. 1991); 31 Tokyo Bay, Japan (Nixon et al. 1986b); Back River, MD (Boynton et al. 1998); 33 Boston Harbor, MA pre-diversion (Nixon et al. 1996); 34 W. Scheldt, Netherlands (Nixon et al. 1996). Figure courtesy of W. Boynton, University of Maryland.

Section 2: Historical summary

General Introduction

This section contains a short history of the Coastal Bays and its watershed. Both pre- and post-European events are covered, and a timeline of major events occurring since the late nineteenth century is included. This historical paper was the result of a review of historical documents and summaries, supplemented by interviews with experts on Coastal Bays history and local citizens. Some of the information is based purely on the observations of some of the interviewees and is thus speculative, but nevertheless illuminating. This historical section was included in the overall assessment in order to provide a framework for how and why ecological change has occurred in this watershed. Such a framework can be used in the context of the current status of water quality, habitat, and living resources to guide future management decisions.

Chapter 2.1 A brief history of the Maryland Coastal Bays

Chapter 2.1

A brief history of the Maryland Coastal Bays

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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. 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: Pleistocene to Holocene

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, harkening the end of the last ice age. The Holocene Epoch began roughly 10,000 year ago with the final retreat of the glaciers. The Coastal Bays started to resemble their present day configuration within the last 5,000 years when sea reached a level approximately six to seven meters (roughly 20 feet) below present mean sea level and started to flood the study area (Figure 2.1.1). Deceleration in sea level rise may have induced the formation of barrier islands, and consequently the bays and marshes behind them. 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 (Biggs1970; 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 were separated from the ocean by bay mouth barrier islands that form adjacent to eroding headlands, a major source of sediments. Further south, away from the eroding headlands, 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 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, *Morone saxatilis*; white perch, *M. americana*; shad, *Alosa* spp.) by weir in the tributaries, leaving no evidence of watercraft other than small dugout canoes. They also collected abundant shellfish 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, although many groups likely moved in and out of the watershed on a regular basis (Hager 1996).

Second contact: 1524 – 1850 A.D.

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° N 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 the dense vegetation forced them 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 British vessel *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. 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.

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 1700's and early 1800's opened and re-opened inlets to Sinepuxent Bay north of Tingles Island (Figure 2.1.2). These inlets provided a brackish environment conducive to oyster (*Crassotrea virginica*) establishment and consequent harvest. However, the area was geographically remote and, until railroads were established in the nineteenth 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 rumrunners in the early twentieth century.

Into the twentieth century

Demographics

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.). 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. Foreshadowing future development of Fenwick Island as a tourist attraction, Scott's Ocean House opened at Green Run in 1869. This seasonal hotel, the first on the island, was a popular with visitors from Mid-Atlantic States. Ocean City was becoming a popular resort destination during this period, with several hotels opened near the beaches. This ultimately caused the demise of Scott's, which closed in 1894. Ocean City did not become an incorporated municipality until 1880, building its first wastewater treatment plant in 1937.

Development proceeded through the twentieth century, 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 1950's and 1960's. 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 doubled between 1940 and 1996 (Table 2.1.1), a fact made more interesting in that nearly three centuries were required to attain the 1940 population (Hager 1996).

Natural Resources

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 (Figure 2.1.2). 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 this navigable inlet, inducing a greater volume of water to flow in and out of the northern Coastal Bays than would have flowed naturally. Subsequent inlet scouring by currents and jetty improvements further increased the hydraulic efficiency of the artificially enhanced inlet. Many watermen believed that the increased salinity would lead to productive oyster harvests. The inlet did have profound effects on the fauna of the Coastal Bays, as the salinity rose to that of ocean water. 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, or at least prevented recovery. 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.

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 seagrass beds where they live (M. Tarnowski, per. comm.). Eelgrass (*Zostera marina*) declined precipitously through the 1930's due to wasting disease and new scallop fisheries never materialized. Recently, bay scallops have been found in all bay segments except Newport Bay, and this range expansion along with increases in sea grass coverage lends hope to their establishment in the Coastal Bays.

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 nineteenth 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 1970's. Recently (1980's through present), catches seem to hover around 1,000,000 total crabs or 1.17 million pounds (hard, soft, and peeler) per year (see Chapter 8.6 for more information). Like bay scallops, seagrass beds are critical habitat for blue crabs. However, there was no apparent decline in crab harvests during the period between the 1930's and early 1980's when sea grasses were absent and then recovering at low densities (Boynton et al. 1993). Also, in the early 1990's, the parasite *Hematodinium* sp. 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 (Boynton et al. 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. 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 (Boynton et al. 1993). Still, 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. Despite no apparent crash in commercial harvest, some long-time residents feel that blue crabs have been harder to find for recreational "chicken-neckers" in recent years (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 1960's through the 1970's, flounder were the most sought after recreational fish (M. Sampson, pers. comm.). Although, some recreational anglers feel that catches of legal-sized flounder have been declining in recent years (B. Abele and M. Sampson, pers. comm.) and targeted levels of abundance have not been reached, the stock is no longer considered overfished. A combination of overfishing and degraded water quality may be to blame for this decline. With catches down, many anglers are shifting to more productive offshore fishing grounds. Since the population crash of this species in 1989, strict management measures through harvest restrictions and seasons have restored much of this resource throughout the mid-Atlantic region.

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 1980's, 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 1970's and into the 1980's, a spring run of monkfish (*Lophius americanus*) occurred on an annual basis (M. Sampson, pers. comm.). The DNR Fisheries Service 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 1970's, 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 variety of 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 Maryland Fisheries 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 much 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; also see Table 2.1.1), with many more permanent residents as opposed to summer visitors (C. Cummins, pers. comm.). Changes in land use will bring about added stresses to the Bays ecosystem (Hager 1996). Proactive management of development and agriculture, 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 recent 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 (1820-2003)

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

<u>1820-1844</u>-Oyster harvest coincident with open inlet. Inlet closed 1844.
<u>1837-</u>First record of wild ponies.
<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.
<u>1879</u>- Hurricane.
<u>1880</u>-Green Run inlet closed. Oysters declined in Sinepuxent. Ocean City incorporated.
<u>1881</u>-Hurricane.
<u>1882</u>-Two hurricanes.
<u>1886</u>-Two hurricanes.
<u>1894</u>-Hurricane off shore.
<u>1908</u>-Seagrass beds present in upper St. Martin River.
<u>1914</u>-A <u>Notes on the Fishes at Ocean City, Maryland</u> was published in the journal *Copeia*.
<u>1916</u>-1787 barrels of "choice" fish harvested.
<u>1920</u>-Sturgeon (caviar) fishery declines.
<u>1921</u>-1921 inlet opened. Improved fish and crab populations.
<u>1928</u>-State begins commercial landings survey of shellfish from bays.
<u>1929</u>-1921 inlet closed.
1930-Eelgrass "wasting disease" begins destroying grass beds.
<u>1933</u>-Hurricane off shore in August. **Storm surge opens Ocean City (OC) Inlet.**
<u>1934</u>-US Army Corps of Engineers stabilizes OC Inlet.

1935-West Ocean City harbor created by US Army Corps of Engineers.
1936-Hurricane off shore.
1937-Ocean City sewage plant opens, discharging into OC Inlet.
1943-Hurricane.
1944-Hurricane and two tropical storms. Fishing (croaker, spot) generally good (through the 1940s).
1948-First dredging of Sinepuxent and Isle of Wight Bays.
1950-Perdue opens Showell chicken processing plant.
1952- State hard clam study.
1953-Hurricane Barbara.
1955-Tropical Storm Connie.
1958-MSX oyster disease first reported. Heyday of lease 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 oyster diseases first mentioned. Tropical Storm Brenda followed by offshore Tropical Storm Donna.
1962-Ash Wednesday Storm. This nor'easter caused much damage along the Eastern Seaboard, including Ocean City. Seventy mph sustained winds and 40-foot seas were recorded over the three-day (five tidal cycle) duration of this storm. Fenwick Island was breached at 71st Street and Assateague Island was breached just south of the Ocean City Inlet.
1964-Assateague State Park established.
1965-Assateague Island National Seashore established. Grey crab disease (*Paramoeba perniciosa*) first reported in Chincoteague Bay.
1967-Tropical Storm Doria.
1968-Ocean Pines development established.
1969-Decent numbers of 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.
1970-Begin to see seagrass recovery in southern Coastal Bays.
1971-Tropical Storm Doria.
1972- DNR Fisheries Service begins routine trawl and seine surveys for finfish and blue crabs. Federal Clean Water Act passed.
1975-Seagrass and scallop declines.
1980-US Army Corps of Engineers identifies need to replenish sand along Ocean City beaches.
1983-First brown pelicans (*Pelecanus occidentalis).* Last commercial oyster harvest. MDE intensive surveys commence.
1985-Offshore hurricane Gloria. Hurricane Danny earlier. Tropical Storm Henri.
1986-VIMS seagrass aerial surveys begin. Observed decline in recreational flounder fishing.
1987-US 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-EPA EMAP* assessment 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. DNR begins long-term hard clam survey (includes scallop numbers). EPA Joint Assessment begins (through 1996). DNR Molluscan Inventory begins.
1995-Maryland Coastal Bays nominated to National Estuary Program.
1996-Japanese shore crabs (*Hemigrapsus sanguineus*) established.
1997-DNR plants bay scallops. DNR Molluscan Inventory study completed. MAIA[f] begins (through 1998). Maryland Coastal Bay Program initiated.
1998-Brown Tide (*Aureococcus anophagefferens*) first detected. DNR begins routine monitoring for *Pfiesteria* at 29 stations throughout the bays and tributaries. DNR plants bay scallops.
1999-Brown Tide. Macroalgae present in large masses.
2000-Brown Tide. Macroalgae. National Coastal Assessment (continuation of EMAP) begins (through 2004).
2001-Brown Tide. Macroalgae. DNR begins routine water quality monitoring at 45 stations throughout the bays and tributaries. Blue crab FMP goes into effect. Restoration of 6.5 acres of salt marsh in Ocean Pines by US Army Corps of Engineers.
2002-Brown Tide. Macroalgae. Scallops found north of OC inlet. Hard clam FMP goes into effect. Exotic species survey completed.
2003-Brown Tide. Large masses of boring sponges present. US Army Corps of Engineers completed replenishment of 1,800,000 cubic yards of sand on Assateague Island. Creation of eight acres of salt marsh on the Isle of Wight (US Army Corps of Engineers) near completion.

* EMAP = Environmental Monitoring and Assessment Program

[f] MAIA = Mid-Atlantic Integrated Assessment

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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. A special thanks is extended to Christopher Spaur of the United States Army Corps of Engineers for providing thoughtful suggestions useful in the preparation and revision of this paper.

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Table 2.1.1
Historical and Projected Population in the Coastal Bays Watershed
Source: Maryland Coastal Bays Program

YEAR	**POPULATION**
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*
projected 2010	60,316
projected 2020	72,117

* These numbers reflect permanent residents only. The number of seasonal residents and vacationers can swell the population to over 300,000 during the summer months.

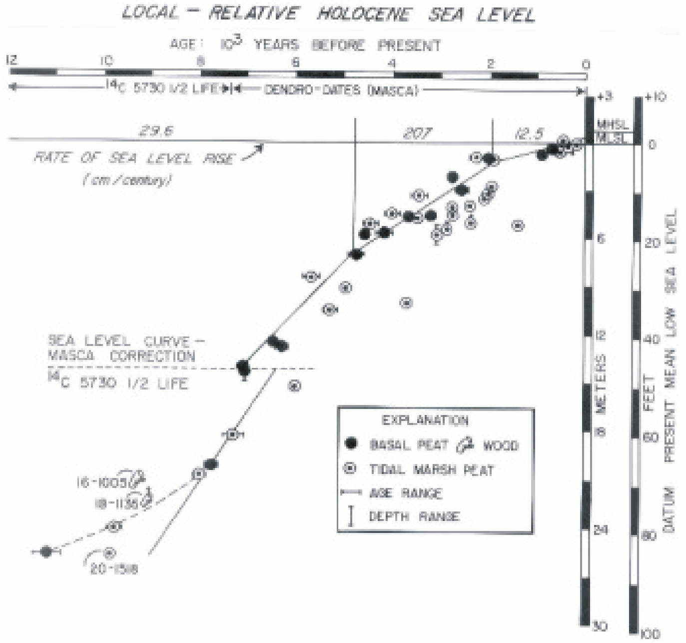

Figure 2.1.1**:** Local relative sea-level rise curve for the Delaware-Maryland coastal zone based on carbon-14 dating of basal and tidal marsh peat, and wood fragments (Kraft et al, 1987; Toscano et al, 1989). MASCA corrections after Ralph et al (1973). Figure taken from Toscano et al (1989).

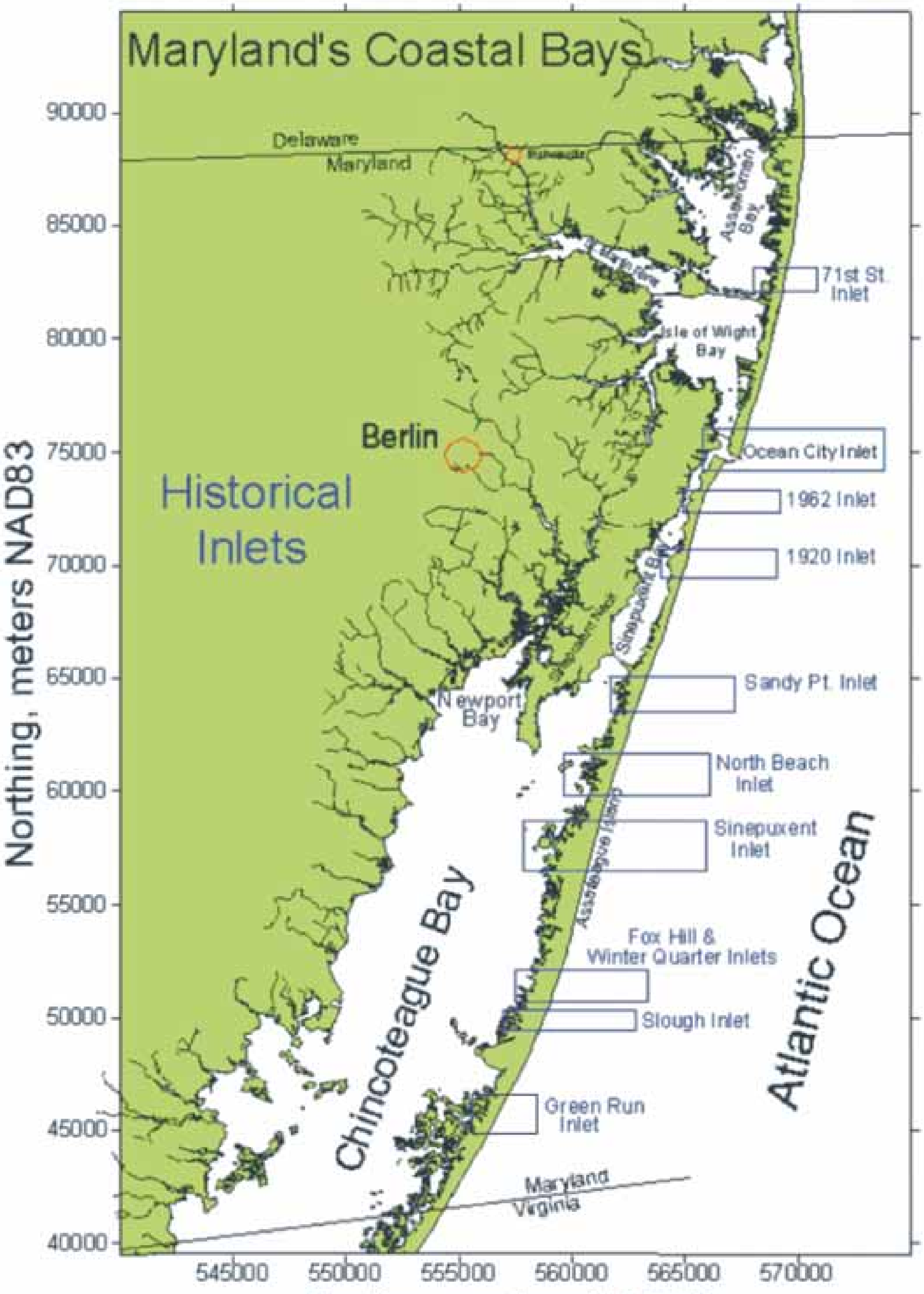

Figure 2.1.2: Historical inlets of Maryland's Coastal Bays. These inlets are described in further detail in the timeline section of the report text.

Section 3: Stream health in the Maryland Coastal Bays

General Introduction

The health of the bays is largely influenced by activities that occur within the watershed (area of land that drains into the bays). Nutrients, sediments and chemicals are transported to the bays via surface runoff (water running over land to creeks, rivers, and streams) and groundwater (water that flows below the earth's surface). Though the latter is the major source of freshwater nutrient input, the relative condition of streams and creeks flowing into the bays is no less relevant to the overall health of the Coastal Bays. In addition, extensive ditching in the watershed for increased drainage has resulted in far more linear feet of waterway than present historically. However, many of these manmade waterways are low quality habitat, built where no natural streams were present in the past. Freshwater streams were monitored for nutrient concentrations and for the condition of living resources (fish and benthic organisms). Many programs, both state and federal, assess stream condition in the Coastal Bays. The chapters in this section summarize the results of some of these studies.

Stream Health Monitoring Objective: To characterize the status and trends of streams in the Coastal Bays.

Chapter 3.1 Stream Nitrate in the Maryland Coastal Bays watershed

Chapter 3.2 Maryland Biological Stream Survey results for the Coastal Bays watershed

Chapter 3.3 Condition of benthic macroinvertebrate communities in the Maryland Coastal Bays watershed

Chapter 3.1

Stream nitrate in the Maryland Coastal Bays watershed

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Abstract

High stream nitrate was observed in all Coastal Bays segments. Stream nitrate is a relative measure of nutrients entering the system. High levels indicate excess inputs from human activities. These inputs are transported to the bays via surface runoff and groundwater. Streams and small creeks are often the initial receptors of pollutants, which then travel downstream to the bays.

Most streams in the Coastal Bays watershed were degraded with excess nitrogen. A majority of streams failed the nitrate threshold suggesting human inputs are high. Streams with more intensive monitoring programs appeared to have more sporadic stormwater inputs and, overall, had higher concentrations of stream nitrate. Many tributaries, even in the relatively undeveloped Chincoteague Bay watershed, had stream nitrate values indicative of enrichment from human activities.

Introduction

Stream nitrate measured during low flow periods is a relative measure of the groundwater nutrients entering the system, while during high flow periods (i.e., storms) it is a measure of land run-off. Stream nitrate monitoring is not a true estimate of loading, as it does not directly evaluate reductions of nutrient inputs due to ecological processes (e.g., denitrification) that may take place as the water enters the stream or flows through wetlands. High anthropogenic inputs were indicated by nitrate values above 1 mg/L (Morgan 1995; Roth et al. 2003).

Methods

Stream nitrate data were collected during special studies by the United States Geological Survey (USGS) and the Maryland Department of Natural Resources (DNR), in conjunction with the Maryland Department of the Environment (MDE). USGS data was collected from southern bay tributaries (Figure 3.1.1) during 1999 and 2000 (Dillow et al. 2002). DNR data were collected through the Maryland Biological Stream Survey (MBSS) program during 2001 (Roth et al. 2003). DNR and MDE conducted a cooperative study collecting weekly samples at Birch Branch (Figure 3.1.1). In addition, four stations included in DNR's routine monthly water quality monitoring program were in non-tidal tributaries (See Section 4).

Management Objective: Decrease nitrogen loading to streams
Indicator: Maximum stream nitrate < 1 mg/L

Results

Maximum stream nitrate concentrations for each station sampled in all of the programs mentioned above are shown in Figure 3.1.1. Broken down by Coastal Bays segment, stream nitrate levels appeared worse in the northern bays (Assawoman Bay, St. Martin River, and Isle of Wight Bay) than in those further south (Newport, Sinepuxent, and Chincoteague Bays). In Assawoman Bay, two stations failed the threshold level and contained very high concentrations of nitrate. All 16 stations in the St. Martin River watershed failed the threshold level with the exception of South Branch (Figure 3.1.1).

Assawoman Bay

The single station in this segment did not meet the nitrate threshold, with very high levels of nitrate (maximum greater than 5 mg/L) (Figure 3.1.1).

St. Martin River

All 16 stations did not meet the nitrate threshold, except one on the South Branch (Figure 3.1.1).

Isle of Wight Bay

All six stations on upper Turville Creek did not meet the nitrate threshold (Figure 3.1.1).

Sinepuxent Bay

Two of the four stations in Sinepuxent Bay watershed met the nitrate threshold (Figure 3.1.1).

Newport Bay

Ten of 14 stations did not meet the nitrate threshold. One station on upper Trappe Creek met the threshold, while three more met the threshold in the southern portion of the watershed (Figure 3.1.1).

Chincoteague Bay

Eight out of 16 sites did not meet the nitrate threshold. Three sites that met the threshold were located in the middle section of the watershed (Figure 3.1.1).

Summary

Most streams, especially in the northern watersheds, were degraded based on nitrate concentration. Upper tributaries were severely nutrient enriched. A majority of streams failed the nitrate threshold suggesting that human inputs were high. Additionally, streams with more intensive monitoring programs appeared to have more sporadic stormwater type inputs and overall had higher concentrations of stream nitrate. The St. Martin River and northern Assawoman Bay watersheds were the most impacted by high nitrate concentrations, while streams flowing into Sinepuxent Bay and northern Chincoteague Bay had the lowest total nitrate concentrations. Since the two former watersheds cross state boundaries (Delaware and Maryland), cooperative agreements to curb nitrate input will be necessary.

Stream nitrate data do not directly evaluate reductions of nutrients because of the often sporadic or ephemeral nature of storm events causing large amounts of run-off. If this is desired, a more specific intensive stormwater monitoring program should be developed. Low flow period and changes in groundwater inputs should be a focus of future monitoring strategies. Another issue is the extensive ditching of many tributaries and creeks that may be allowing groundwater to enter streams faster, thus decreasing the filtration normally encountered before entering the bays. While documented, further work on management options for this problem is warranted.

Acknowledgements

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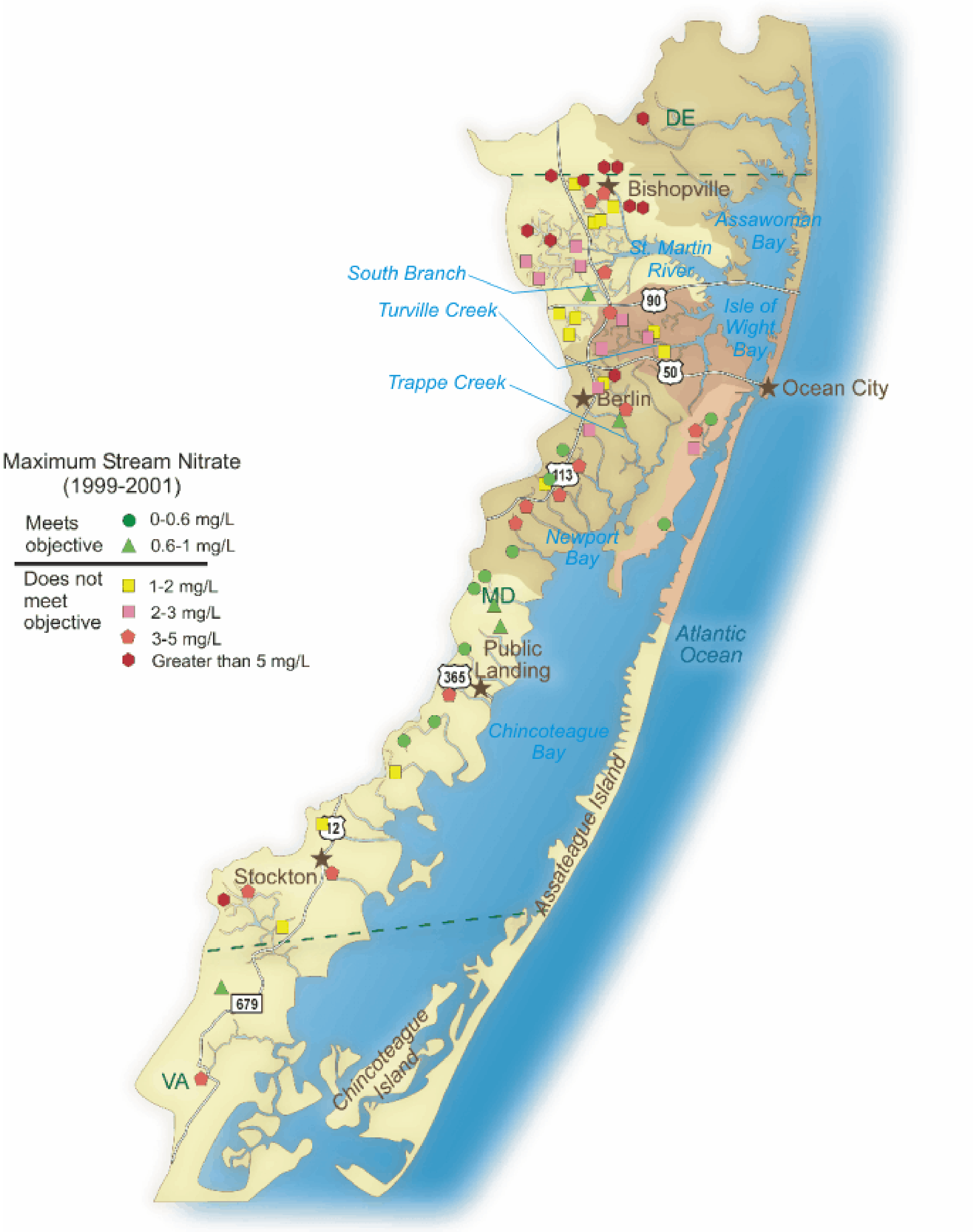

Figure 3.1.1: Maximum total stream nitrate (mg/L) measured by USGS in 1999 and 2000 and DNR/MDE (MBSS) in 2001 for tributaries in the Coastal Bays watershed. Coastal Bays segments are shown as well as individual streams indicated in the text.

Chapter 3.2

Maryland Biological Stream Survey results for the Coastal Bays watershed

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Abstract

Biological community condition showed that streams were degraded. To report overall stream health, freshwater fish and benthic indices of biotic integrity (IBI) were calculated for all sites with adequate data. These IBIs rated stream health according to ecological characteristics of fauna found in that stream. Fish and benthic organisms indicated most streams in the Coastal Bays were degraded. Most fauna found in the stream were classified as pollution-tolerant. Benthic index results from 59 sites rated most sites as either poor (15%) or very poor (75%) with the remaining sites (10%) rated fair. Freshwater fish index results from seven sites rated most sites as very poor (14%) or poor (43%), while 43% rated fair. Impacts to the biota of Coastal Bays streams were likely the result of physical habitat modification (e.g., ditching). 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.

Introduction

The Maryland Biological Stream Survey (MBSS) monitored freshwater streams throughout the state. Data were collected on physical habitat, water chemistry, and invertebrate and fish communities. A total of 15 fish species (Table 3.2.1) were sampled in Coastal Bays streams, with species counts ranging from seven at two sites in Newport Bay and one site in Isle of Wight Bay, to no fish at one site in Newport Bay and one site in Chincoteague Bay. The average number of species among all Coastal Bays sites was 4.6 and the greatest number of individual fish per site (446) was sampled at a site in Chincoteague Bay. The average number of fish per site among all Coastal Bays sites was 160. The dominant fish species was American eel (*Anguilla rostrata*), averaging 34 fish per site, while the mud sunfish (*Acantharchus pomotis*) was the most rare species (0.1 fish per site on average).

Table 3.2.1: List of fish species collected in the Maryland Coastal Bays during the Maryland Biological Stream Survey. Tolerance to poor water quality and status as native or introduced species is also listed. NC=not classified.

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
Creek chubsucker, *Erimyzon oblongus*	NC	Native
Eastern mudminnow, *Umbra pygmaea*	Tolerant	Native
Golden shiner, *Notemigonus crysoleucas*	Tolerant	Native
Inland silverside, *Menidia beryllina*	NC	Native
Largemouth bass, *Micropterus salmoides*	Tolerant	Introduced
Mosquitofish, *Gambusia holbrooki*	NC	Native
Pirate perch, *Aphredoderus sayanus*	Tolerant	Native
Pumpkinseed, *Lepomis gibbosus*	Tolerant	Native
Redfin pickerel, *Esox americanus*	Tolerant	Native
Tessellated darter, *Etheostoma olmstedi*	Tolerant	Native
Mud sunfish, *Acantharchus pomotis*	Intolerant	Native (State listed as Rare)

Seventy genera of benthic macroinvertebrates were sampled at MBSS sites (Table 3.2.2). The number of genera per site averaged 16.5 and ranged from eight to 27. Dominant taxa included clams (*Sphaerium* sp.), isopods (*Caecitodea* sp., *Crangonyx* sp.), midges (*Cricotopus/Orthocladius*, *Polypedilium* sp.), and black flies (*Simulium* sp.). Stream Waders, a MBSS volunteer program, sampled 66 families of benthic macroinvertebrates, with family richness ranging from four to 20.

Table 3.2.2: List of benthic macroinvertebrate genera collected in the Maryland Coastal Bays during the Maryland Biological Stream Survey. Tolerance to poor water quality is also listed. NC=not classified.

Taxon	**Tolerant or sensitive**	**Taxon**	**Tolerant or sensitive**
Atrichopogon	Tolerant	*Microtendipes*	Tolerant
Bezzia	Tolerant	*Musculium*	Tolerant
Caecidotea	Tolerant	*Nyctiophylax*	Sensitive
Calopteryx	Tolerant	*Oecitis*	Tolerant
Cheumatopsyche	Tolerant	*Orthocladius*	Tolerant
Chironomus	Tolerant	*Paraleptophlebia*	Sensitive
Chrysops	Tolerant	*Parametriocnemus*	Tolerant
Cnephia	NC	*Paratanytarsus*	Tolerant
Conchapelopia	Tolerant	*Peltodytes*	Tolerant
Corynoneura	Tolerant	*Phaenopsectra*	Tolerant
Crangonyx	Tolerant	*Physella*	Tolerant
Cricotopus	Tolerant	*Pisidium*	Tolerant
Cricotopus/Orthocadius	Tolerant	*Platycentropus*	NC
Cryptotendipes	Tolerant	*Polypedilum*	Tolerant
Culicoides	Tolerant	*Procambarus*	Tolerant
Dicrotendipes	Tolerant	*Procladius*	Tolerant
Diplocladius	Tolerant	*Prosimulium*	Tolerant
Dubiraphia	Tolerant	*Prostoia*	Sensitive
Dugesia	Tolerant	*Prostoma*	Tolerant
Endochironomus	Tolerant	*Pseudolimnophila*	Tolerant
Gammarus	Sensitive	*Ptilostomis*	Tolerant
Glytotendipes	Tolerant	*Rheocricotopus*	Tolerant
Habrophlebia	NC	*Simulium*	Tolerant
Hemerodromia	NC	*Sphaerium*	Tolerant
Heterotrissocladius	Tolerant	*Stagnicola*	Tolerant
Hydrobaenus	Tolerant	*Stegopterna*	NC
Hydroporus	Tolerant	*Stenelmis*	Tolerant
Hydropsyche	Tolerant	*Symoptthastia*	Tolerant
Ironoquia	NC	*Synurella*	NC
Labrudinea	NC	*Tanytarsus*	Tolerant
Lepidostoma	Sensitive	*Thienemanniella*	Tolerant
Limnodrilus	Tolerant	Thienemannimyia group	Tolerant
Lype	NC	*Tribelos*	Tolerant
Menetus	NC	*Zavrelimyia*	Tolerant
Micropsectra	Tolerant		

Data sets

Twelve sites were sampled in the Coastal Bays watersheds during 1997 and 2001 as part of the Maryland Biological Stream Survey (MBSS). Fish, benthic macroinvertebrate, and water samples were collected and physical habitat was assessed according to methods described in Kazyak (2001) and Boward and Friedman (2000). Also, spring benthic macroinvertebrate samples were collected (Boward 2000; Boward and Bruckler 2002) at 47 sites as part of DNR's volunteer Stream Waders Program. Table 3.2.3 summarizes MBSS and Stream Waders sampling in Coastal Bays watersheds.

Table 3.2.3: Summary of MBSS and Stream Waders sampling in the Coastal Bays.

Site type	Year	Number of sites	Site selection method	Watersheds sampled
MBSS	1997	3	Non-random	Chincoteague Bay, Isle of Wight Bay, Newport Bay
MBSS	2001	9	Random	Chincoteague Bay, Isle of Wight Bay, Newport Bay
Stream Waders	2001	47	Non-random	Assawoman Bay, Chincoteague Bay, Isle of Wight Bay, Newport Bay, Sinepuxent Bay

Management Objective: Healthy Stream Fauna

MBSS Indicator 1: Fish IBI ≥ 4 (thresholds described below)
MBSS Indicator 2: Invertebrate IBI ≥ 4 (thresholds described below)

Analyses

To report overall stream health, fish and benthic macroinvertebrate indices of biotic integrity (IBI) were calculated for all sites that had adequate data. The MBSS fish and benthic macroinvertebrate IBIs rate stream health according to ecological characteristics of each assemblage. Table 3.2.4 explains the ranges of the IBI and the corresponding narrative stream health ratings. Reference conditions for the Coastal Bays were defined as those from streams having minimal anthropogenic disturbance, based on thresholds established for water chemistry, physical habitat, and catchment land use. The following 12 criteria were defined (Roth et al. 2000):

- pH ≥ 6 or blackwater stream (pH < 6 and DOC ≥ 8 mg/L)
- ANC ≥ 50 µeq/L
- DO ≥ 4 ppm
- nitrate ≤ 300 µeq/L (4.2 mg/L)

- urban land use ≤ 20% of catchment area
- forest land use ≥ 25% of catchment area
- remoteness rating: optimal or suboptimal
- aesthetics rating: optimal or suboptimal
- instream habitat rating: optimal or suboptimal
- riparian buffer width ≥ 15 m
- no channelization
- no point source discharges

Table 3.2.4: Rankings of IBI scores and corresponding comparative measures in relation to reference conditions.

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.

Fish IBIs (FIBI) were calculated for seven of the 12 sites in the Coastal Bays watersheds. FIBIs were not calculated for streams with upstream catchment sizes less than 300 acres, dry streams, or blackwater streams. Benthic macroinvertebrate IBIs (BIBI) were calculated for 59 sites (12 MBSS and 47 Stream Waders). A family level BIBI was calculated for spring macroinvertebrate samples collected through the Stream Waders program.

Results

FIBIs from five sites ranged from 1.8 (very poor) to 3.3 (fair) (Figure 3.2.1). BIBI values ranged from 1.0 (very poor) to 3.6 (fair) (Figure 3.2.2). The percentage of sites in each IBI category is shown in (Figure 3.2.3). Please note that not all streams mentioned in the text and tables are shown on the figure maps.

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, while MBSS sites contain either a county or watershed code. NA in the BIBI and FIBI

Stream Condition columns indicates no data collected. UT refers to an unnamed tributary of the named waterway.

Assawoman Bay – A single Stream Waders sample was taken in the Assawoman Bay watershed (Table 3.2.5). The BIBI for this site was 1.29 (very poor).

Table 3.2.5: 2001 MBSS results for the Assawoman Bay watershed.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0689-3	BACK CREEK	1.29	very poor	NA	NA

Isle of Wight Bay/St. Martin River – Twenty-two total sites were sampled in the Isle of Wight Bay Watershed: five by MBSS and 18 by Stream Waders. The three FIBIs range from fair (Crippen Branch off Turville Creek) to poor (South Branch) to very poor (Bishopville Prong upper tributary) (Table 3.2.6). Two sites were rated fair by the BIBI – Bishopville Prong upper tributary and South Branch. All others were rated poor (5%) or very poor (86%).

Table 3.2.6: 2001 MBSS results for the Isle of Wight Bay watershed.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
0692-2	CAREY BRANCH	1	very poor	NA	NA
0692-13	PERKINS-BISHOPVILLE UT1*	1	very poor	NA	NA
0691-1	BIRCH BRANCH	1.29	very poor	NA	NA
0692-14	GODFREY AG. DITCH	1.29	very poor	NA	NA
0692-1	CAREY BRANCH	1.29	very poor	NA	NA
0692-6	BISHOPVILLE PRONG UT1 TO UT2	1.29	very poor	NA	NA
0691-7	CHURCH BRANCH	1.57	very poor	NA	NA
0692-7	LAMBARKINS BRANCH	1.57	very poor	NA	NA
0692-8	LAMBKIWS CREEK	1.57	very poor	NA	NA
0692-11	MOSES CREEK	1.57	very poor	NA	NA
0692-12	PERKINS CREEK	1.57	very poor	NA	NA
0692-4	SLAB BRIDGE PRONG	1.57	very poor	NA	NA
0692-9	BISHOPVILLE PRONG UT	1.57	very poor	NA	NA
ISLE-105-R-2001	CRIPPEN BRANCH	1.57	very poor	NA	NA
ISLE-107-R-2001	CRIPPEN BRANCH	1.57	very poor	NA	NA
ISLE-120-R-2001	CRIPPEN BRANCH	1.57	very poor	3.25	fair
0692-10	BISHOPVILLE PRONG UT	1.86	very poor	NA	NA
0690-2	CRIPPEN BRANCH	1.86	very poor	NA	NA
0691-4	MIDDLE BRANCH	1.86	very poor	NA	NA
0692-5	SLAB BRIDGE PRONG	1.86	very poor	NA	NA
0692-3	CAREY BRANCH	2.71	poor	NA	NA
WO-S-022-935-97	BISHOPVILLE PRONG UT	3	fair	1.75	very poor

ISLE-115-R-2001	CHURCH BRANCH	3	fair	2.75	poor

* Site is on an unnamed tributary ditch to an unnamed ditch connecting Bishopville Prong and Perkins Creek.

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

Table 3.2.7: 2001 MBSS results for the Sinepuxent Bay watershed.

SITE	**STREAM NAME**	**BENTHIC IBI**	**STREAM CONDITION**	**FISH IBI**	**STREAM CONDITION**
0681-2	GRAY'S COVE UT	1.29	very poor	NA	NA
0681-3	GRAY'S CREEK UT	1.29	very poor	NA	NA
0681-1	BAT CREEK	1.57	very poor	NA	NA

Newport Bay – Three MBSS (two with FIBIs) and six Stream Waders sites were sampled in the Newport Bay watershed. The two FIBIs reflect fair and poor conditions in Kitts Branch and Bottle Branch, respectively (Table 3.2.8). Two streams (22%) were rated fair by the BIBI. All other streams were rated poor (33%) or very poor (45%) by the BIBI.

Table 3.2.8: 2001 MBSS results for the Newport Bay watershed.

SITE	**STREAM NAME**	**BENTHIC IBI**	**STREAM CONDITION**	**FISH IBI**	**STREAM CONDITION**
NEWP-110-R-2001	TUKESBURG BRANCH	1.29	very poor	NA	NA
0683-3	PORTER CREEK	1.57	very poor	NA	NA
0685-1	KITTS BRANCH	1.57	very poor	NA	NA
WO-S-998-936-97	BOTTLE BRANCH	1.86	very poor	2.75	poor
0683-2	POPLARTOWN BRANCH	2.14	poor	NA	NA
0682-2	MARSHALL CREEK	2.43	poor	NA	NA
NEWP-116-R-2001	KITTS BRANCH	2.71	poor	3	fair
0683-1	NEWPORT CREEK	3.00	fair	NA	NA
0682-1	MASSEY BRANCH	3.29	fair	NA	NA

Chincoteague Bay - Four MBSS (two with FIBIs) and 20 Stream Waders sites were sampled in the Chincoteague Bay Watershed. FIBIs reflect fair and poor conditions in Payne Ditch (Big Millpond) and Powell Creek, respectively (Table 3.2.9). BIBIs indicate poor conditions in both streams. Two streams (8%; Paradie Branch and Riley Creek) were rated fair by the BIBI. All other streams were rated poor (21%) or very poor (71%) by the BIBI.

Table 3.2.9: 2001 MBSS results for the Chincoteague Bay watershed.

SITE	STREAM NAME	BENTHIC IBI	STREAM CONDITION	FISH IBI	STREAM CONDITION
CHIN-112-R-2001	FIVEMILE BRANCH	1.00	very poor	NA	NA
0671-2	RILEY CREEK	1.00	very poor	NA	NA
0678-5	SCARBORO CREEK	1.00	very poor	NA	NA
0680-3	WATERWORKS CREEK	1.00	very poor	NA	NA
0672-1	MARSHALL DITCH	1.29	very poor	NA	NA
0678-4	SCARBORO CREEK UT	1.29	very poor	NA	NA
0679-1	POORHOUSE BRANCH UT	1.29	very poor	NA	NA
0680-2	WATERWORKS CREEK UT2	1.29	very poor	NA	NA
0675-2	BRIMER GUT	1.57	very poor	NA	NA
0674-3	PIKES CREEK	1.57	very poor	NA	NA
0674-1	PIKES CREEK UT TO UT	1.57	very poor	NA	NA
0674-2	PIKES CREEK UT	1.57	very poor	NA	NA
0680-5	WATERWORKS CREEK UT1	1.57	very poor	NA	NA
CHIN-103-R-2001	WATERWORKS CREEK	1.57	very poor	NA	NA
0671-5	HANCOCK CREEK	1.86	very poor	NA	NA
0679-2	ROBINS CREEK UT TO UT	1.86	very poor	NA	NA
0680-4	WATERWORKS CR UT1	1.86	very poor	NA	NA
0672-2	LITTLE MILL CREEK	2.14	poor	NA	NA
0671-4	POWELL CREEK	2.14	poor	NA	NA
WO-S-999-937-97	PAYNE DITCH	2.14	poor	3.25	fair
0675-1	BRIMER GUT	2.43	poor	NA	NA
CHIN-119-R-2001	POWELL CREEK	2.71	poor	2.25	poor
0672-3	PARADIE BRANCH	3.57	fair	NA	NA
0671-3	RILEY CREEK	3.57	fair	NA	NA

Summary

Fish and benthic macroinvertebrate data from MBSS and Stream Waders sampling suggest that most streams in the Coastal Bays were degraded. Most taxa from both assemblages were 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 resulted from physical habitat modification (e.g., ditching). 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 report (Roth et al. 2003).

Acknowledgements

The MBSS would like to thank all of the Stream Wader and MBSS volunteers who helped collect data in the Coastal Bays.

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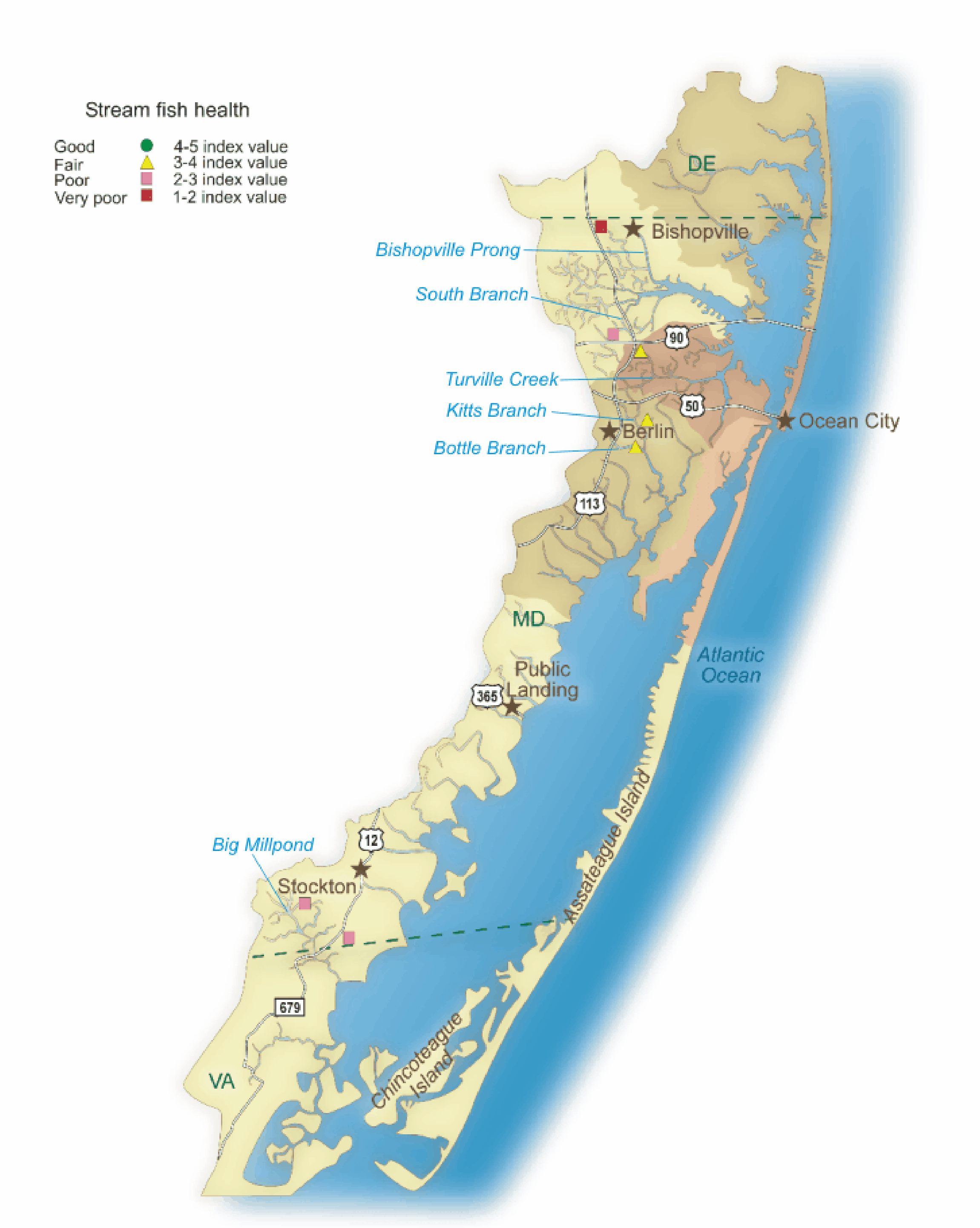

Figure 3.2.1: Fish Index of Biotic Integrity (FIBI) for freshwater streams of the Coastal Bays watershed sampled in 2001. Streams with watersheds less than 300 acres were not calculated for FIBI.

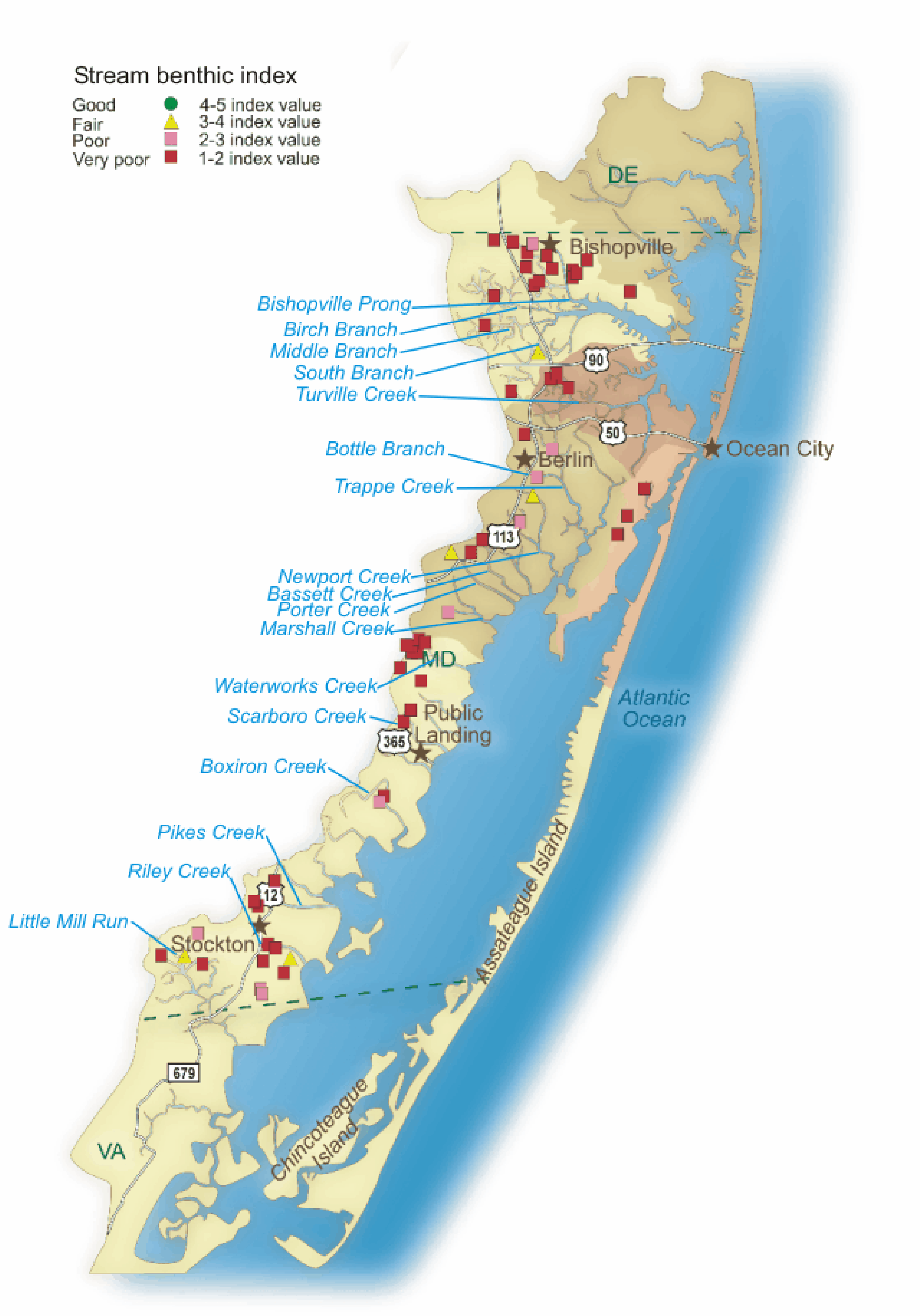

Figure 3.2.2: Benthic Index of Biotic Integrity (BIBI) for freshwater streams of the Coastal Bays watershed sampled in 2001.

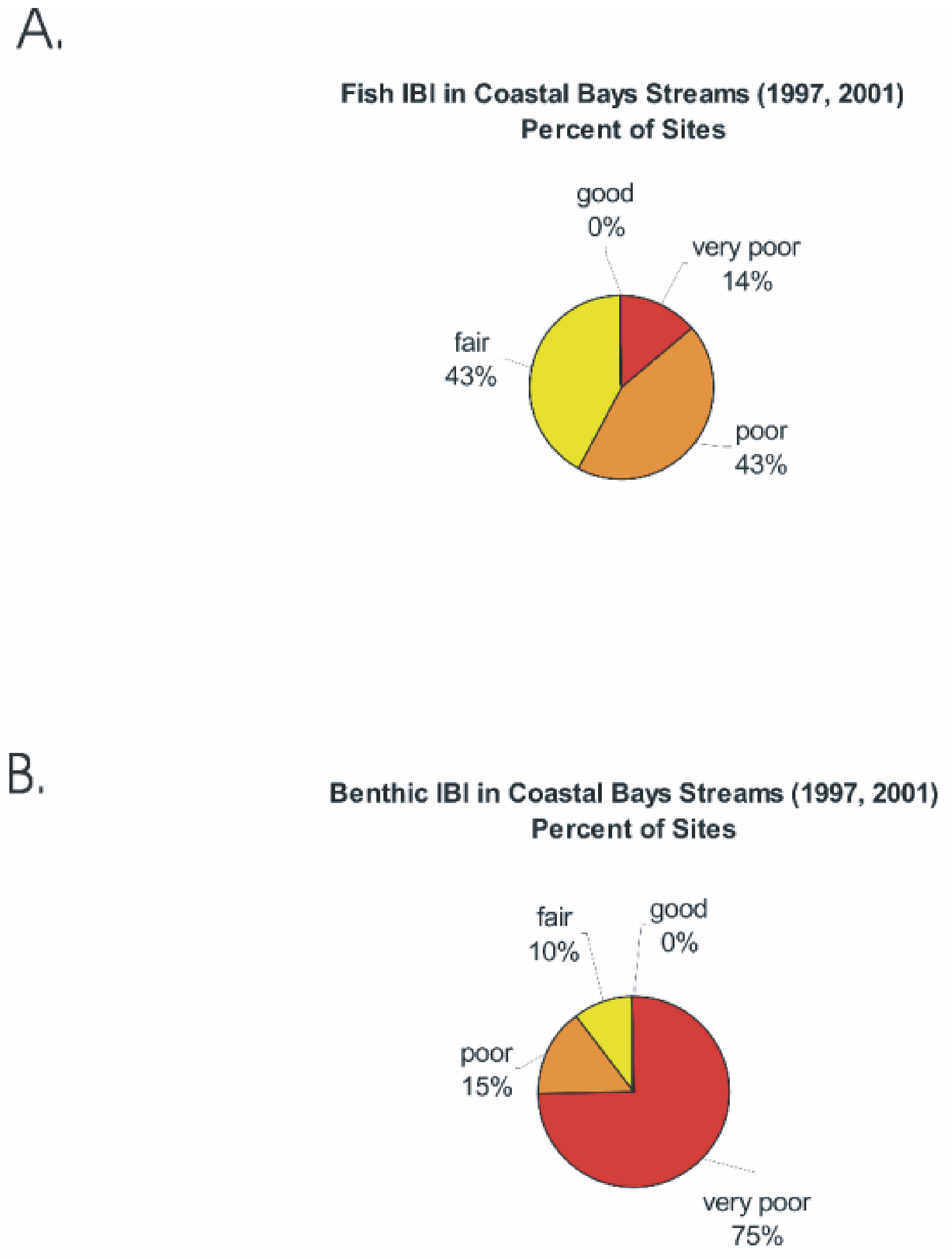

Figure 3.2.3: A.) Percent of sampling sites falling within each of the Fish Index of Biotic Integrity condition categories for 2001 MBSS sampling data. B.) Percent of sampling sites falling within each of the Benthic Index of Biotic Integrity condition categories for 2001 MBSS and Stream Waders sampling data.

Chapter 3.3

Trends in freshwater benthic macroinvertebrate communities in the Maryland Coastal Bays watershed

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Abstract

Current conditions of freshwater benthic communities help determine long-term water quality trends. Freshwater benthic communities in the Coastal Bays indicated a strong improvement in water quality from the very poor to lower 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. There was no significant trend in fair water quality at Birch Branch; Bottle Branch and Trappe Creek stations showed a slight improvement in water quality from the poor to the lower fair range. Both sites showed an increase in taxa number, and Bottle Branch also showed an improvement in biotic index values. Some improvements in water quality were indicated by the benthic community, but conditions remain fairly degraded in the Coastal Bays watershed.

Introduction

Freshwater benthic macroinvertebrate data were collected 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 specific site as a measure of water quality at that site. This contrasts with MBSS 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 1: 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 community indicated a strong improvement in water quality from the very poor to lower 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 and biotic and diversity indices). The benthic community indicated no significant trend in fair water quality at Birch Branch (BIH0009) (Figure 3.3.2).

Newport Bay – Benthic macroinvertebrate communities at both Bottle Branch (BOB0001) and Trappe Creek (TRC0059) stations showed a slight improvement in water quality from the poor to the lower fair range. Both sites showed an increase in taxa number (and Bottle Branch also showed an improvement in biotic index values (Figure 3.3.3).

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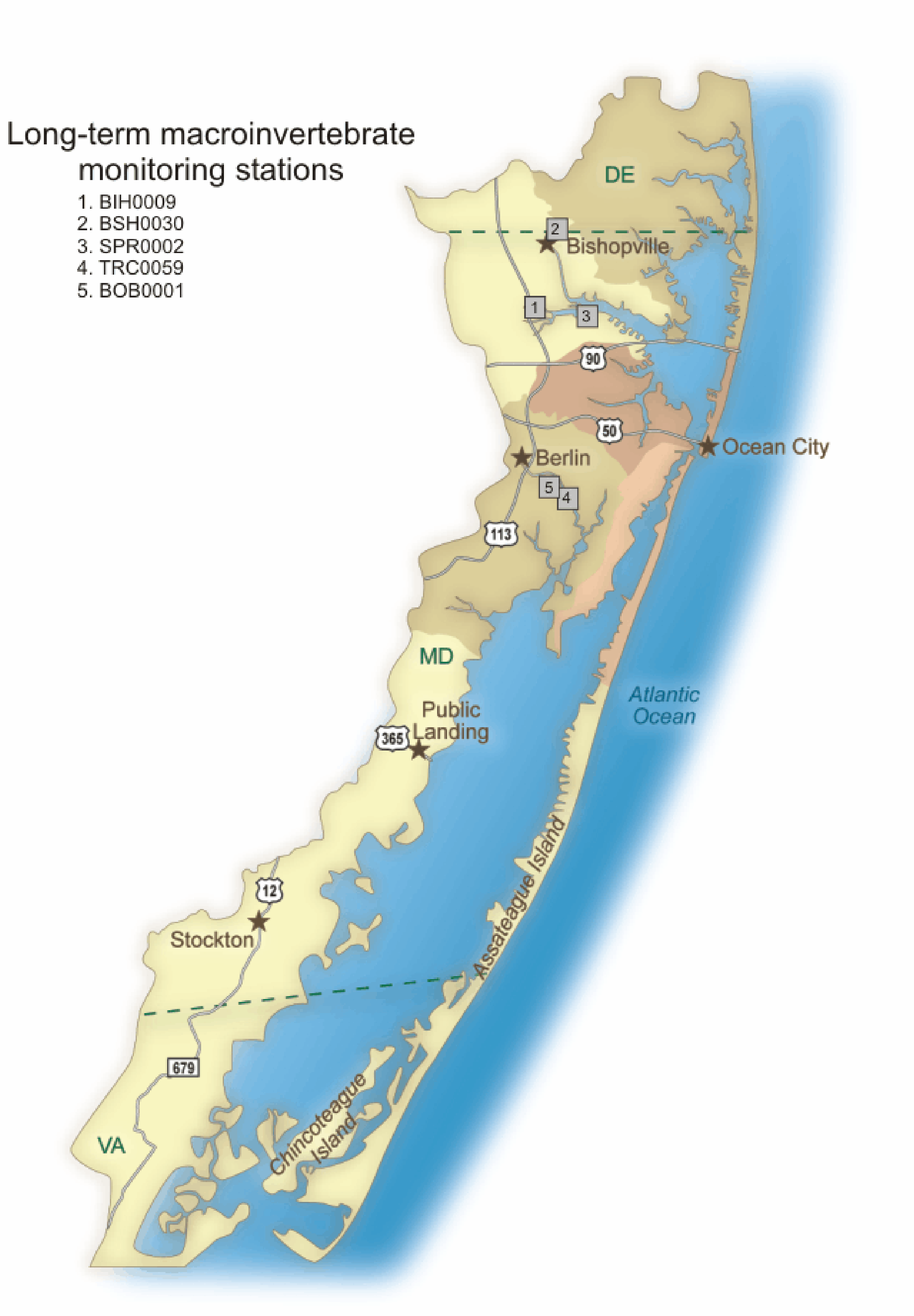

Figure 3.3.1: Locations of long-term macroinvertebrate monitoring stations in the Coastal Bays.

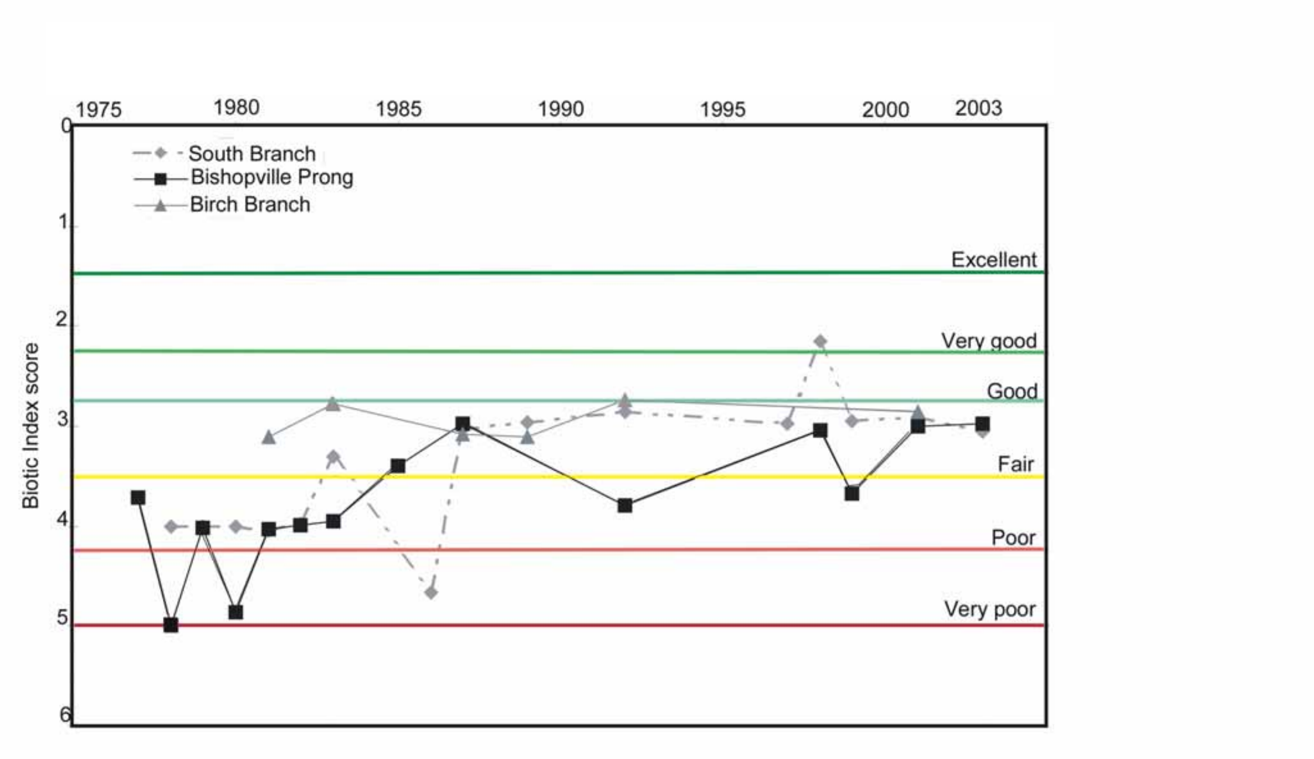

Figure 3.3.2: Trends in freshwater macroinvertebrate community over time in three tributaries of the St. Martin River. Cut-off points and ranking categories were developed through an amalgamation of four commonly used diversity indices (see text). The biotic index score shown here is the modified Hilsenhoff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

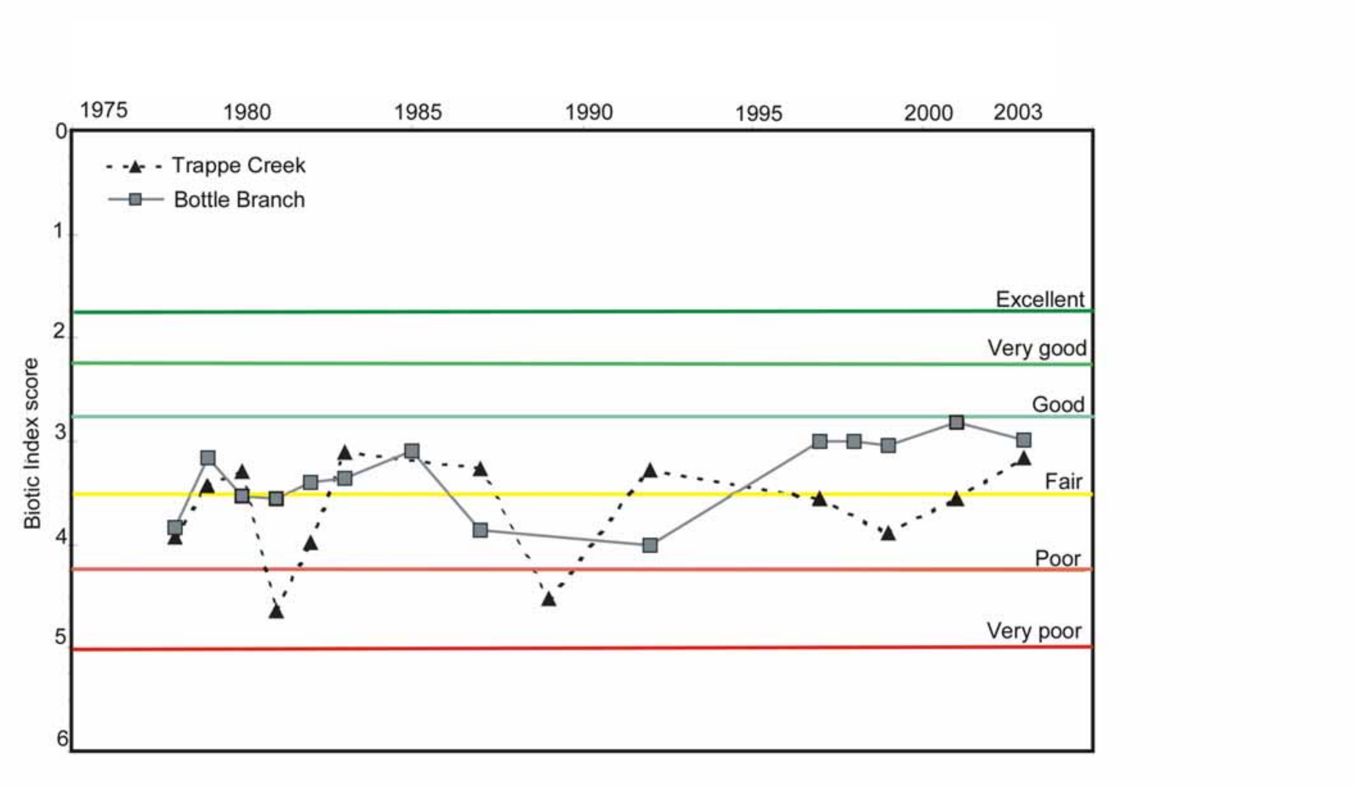

Figure 3.3.3: Trends in freshwater macroinvertebrate community over time in two tributaries of Newport Bay. Cut-off points and ranking categories were developed through an amalgamation of four commonly used diversity indices (see text).The biotic index score shown here is the modified Hilsenhoff biotic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

Section 4: Water quality in the Maryland Coastal Bays

General Introduction

Increased nutrients to the Coastal Bays lead to degraded water quality and ecosystem health. Increased phytoplankton blooms (measured as water column chlorophyll-*a*) and related swings in dissolved oxygen (DO) are symptoms of ecosystem degradation. Measuring nutrient concentrations in the water column over time allows managers to track changes in nutrient inputs.

As the major source of freshwater to the bays, groundwater is also a dominant source of nutrients. Groundwater flows much slower than surface runoff (several years to decades compared to hours to days); therefore, nutrients entering the bays may be from actions that happened on land many years ago. Hence, improvements to water quality as a result of management actions taken on land may take a minimum of five to ten years.

Data Sets

Routine water quality monitoring includes the National Park Service at Assateague Island National Seashore (ASIS), Maryland Department of Natural Resources (DNR) and the Maryland Coastal Bays Program (MCBP) Volunteer Water Quality Monitoring Program. ASIS measured water quality parameters monthly at 18 stations in the southern Coastal Bays since 1987 (Figure 4.1). DNR measured water quality monthly at 28 sites in the St. Martin River, Isle of Wight Bay, and Newport Bay segments since 1998 and 17 sites in Assawoman Bay, Isle of Wight Bay and Chincoteague Bay since 2001 (Figure 4.1). All stations are tidal, except for five DNR stations, and all are monitored in accordance with EPA approved Quality Assurance Plans and in conjunction with the MCBP Eutrophication Monitoring Plan (Wazniak 1999). MCBP volunteers have collected samples at 25 stations monthly since 1996 (Figure 4.1).

All programs recorded on-site water quality indicator values, such as Secchi depth and salinity, and collected samples to send to laboratories for nutrient and chlorophyll analyses. DNR samples were analyzed by the University of Maryland Center for Environmental Science (UMCES) Chesapeake Biological Laboratory for all nutrient indicators while chlorophyll is analyzed at the Maryland Department of Health and Mental Hygiene (DHMH). ASIS and MCBP samples were analyzed by UMCES Horn Point Laboratory for nutrient and chlorophyll indicators. Quality assurance and quality control measures at these laboratories were virtually identical, allowing for comparability between the different sampling programs. However, no split-sample testing on ASIS and DNR samples was conducted, although the three laboratories have been evaluated as part of the Chesapeake Bay Program quality assurance protocol and not found to differ significantly.

Water Quality Analyses

Status is defined as the measure of current condition (most recent three years) at a station compared to scientifically based thresholds. Current status values were compared to threshold levels determined by the MCBP STAC using non-parametric statistics.

Trend is defined as the measure of how the system has been changing over time, either improving or worsening. Status and trend calculations were based on observed data (i.e., no flow-adjustment was made to the data). For a full description of water quality status and trend analyses, see Ebersole et al. (2002) and Gilbert (1987).

Water Quality Monitoring Objective: To characterize the status and trends in ambient water quality in the Coastal Bays.

Chapter 4.1: Nutrient status and trends in the Maryland Coastal Bays

Chapter 4.2: Algae status and trends in the Maryland Coastal Bays

Chapter 4.3: Dissolved oxygen status and trends in the Maryland Coastal Bays

Chapter 4.4: Development of a Water Quality Index for the Maryland Coastal Bays

Chapter 4.5: Benthic chlorophyll measurements

References

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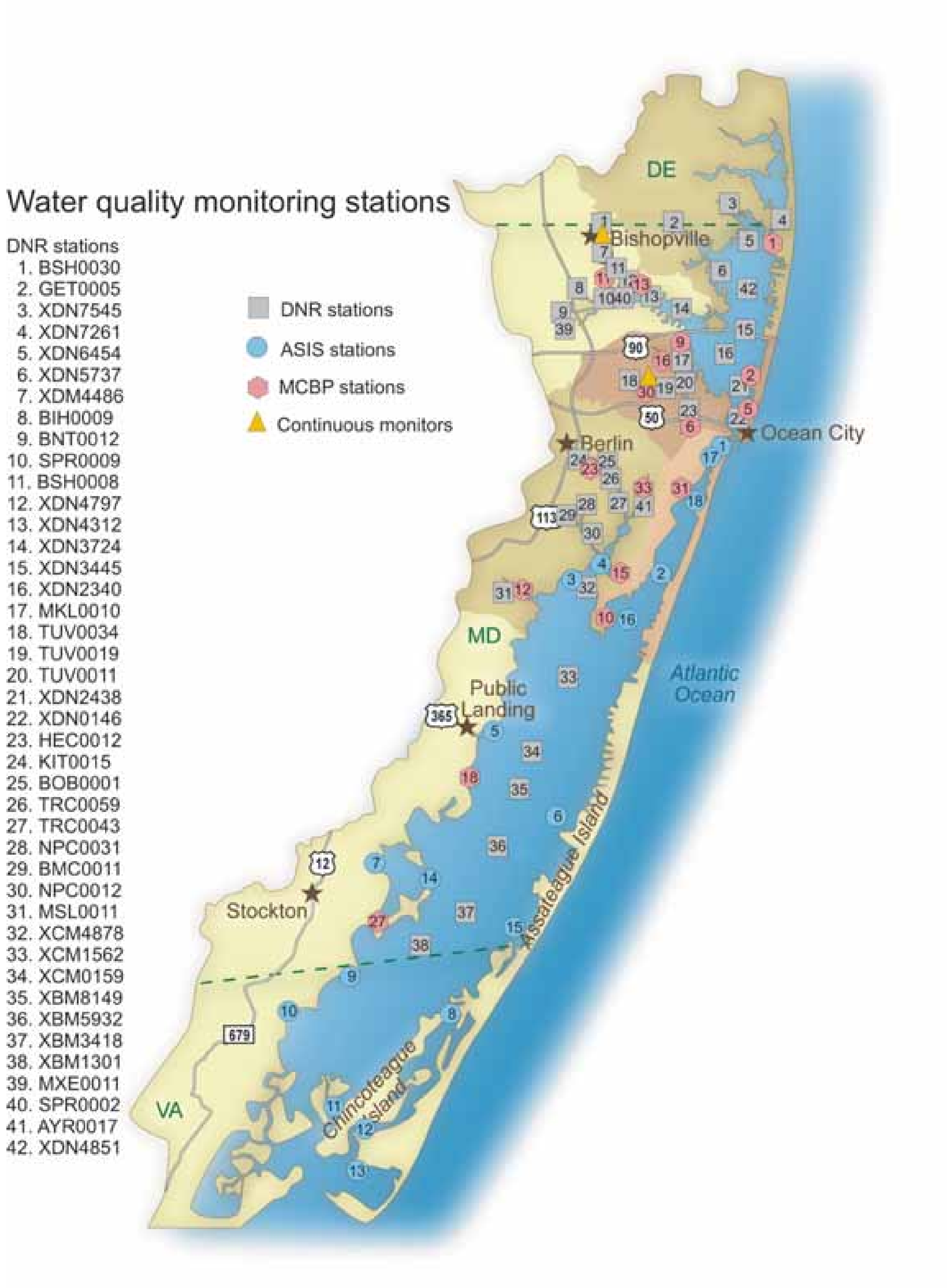

Figure 4.1: Map showing water quality stations in the Maryland Coastal Bays (including the Virginia portion of Chincoteague Bay). DNR station names are listed in the legend. National Park Service, Assateague National Seashore (ASIS) and Maryland Coastal Bays Program Volunteer (MCBP) stations are named by number as on the map.

Chapter 4.1

Nutrient status and trends in the Maryland Coastal Bays

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Abstract

Total nitrogen (TN) and total phosphorus (TP) concentration data from the 2001 through 2003 Coastal Bays water quality monitoring program (Maryland Department of Natural Resources and Assateague Island National Seashore) were analyzed for status. TN and TP concentration data from Assateague Island National Seashore only were analyzed for trends (DNR data sets were not of long enough duration). Results indicated that the upper tributaries, mostly in the northern Coastal Bays, and Newport Bay were severely enriched with nitrogen. The southern Coastal Bays, Sinepuxent and Chincoteague, had the lowest TN concentrations. Phosphorus enrichment appeared to be more widespread. The only segments demonstrating phosphorus levels suitable for seagrass growth were Sinepuxent and Chincoteague Bays.

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. However, nutrient inputs are often sporadic or ephemeral, as when a storm event causes large amounts of run-off. Non-point nutrient inputs are the major sources of nutrients, nitrogen and phosphorus, to the Coastal Bays. Point sources are estimated to account for only 4% of the total nutrient inputs (Boynton 1993). Non-point sources include agriculture (fertilizer and animal waste), atmospheric deposition, septic systems, and natural sources (wetlands, marshes, and forests). Total nitrogen (TN) and total phosphorus (TP) were used as indicators to reduce variability associated when measuring dissolved nutrients only.

Nutrient concentrations can be affected by inputs from a sewage treatment plant, agricultural run-off, and atmospheric deposition, the latter of which brings in nutrients from outside the watershed.

Data Sets

Several water quality monitoring programs were implemented in the Coastal Bays (see Chapter 1.1). Those conducted by the Maryland Department of Natural Resources (DNR) and the National Park Service at Assateague Island National Seashore (ASIS) were used for nutrient analysis in this report (the Maryland Coastal Bays Program volunteer monitors did not collect TN or TP data). Figure 4.1.1 shows the locations of each DNR and ASIS station monitored between 2001 and 2003. 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 reduce bay water concentrations of nitrogen and phosphorus.

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

Analyses

Status

Median concentrations of TN and TP were determined for the three-year period between 2001-2003 for each monitoring station (Figure 4.1.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed criteria for threshold categories based on living resources indicators, most notably seagrass (see under Management Objective above). Based on these criteria, threshold categories were determined (Table 4.1.1). Each median value was compared to each cutoff value from Table 4.1.1 by non-parametric Wilcoxon test. Those medians that were significantly different at p=0.01 from the two cutoffs between which they fell were considered statistically significant overall.

Table 4.1.1: Threshold category values for TN and TP 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 suggested by STAC.

Threshold criteria category	TN cutoff values for threshold category	TP cutoff values for threshold category
Better than seagrass objective	< 0.55 mg/L	< 0.025 mg/L
Meets seagrass objective	**< 0.64 mg/L**	**< 0.037 mg/L**
Does not meet seagrass objective	**< 1 mg/L**	< 0.043 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

Trends

Trend analyses were utilized to compare the effect of time on water quality parameters. Only ASIS stations were used because DNR stations did not have a long enough data record for a robust trend analysis and MCBP stations were not analyzed for TN or TP. The Seasonal Kendall test was used to identify 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 0.01 was used to reduce the chance of type I error.

Status of nutrient concentrations

The status of TN and TP concentrations in each Coastal Bays segment are discussed below. Please refer to Figure 4.1.1 for individual stations mentioned in the text.

Assawoman Bay

None of the seven stations met TN or TP seagrass thresholds. One station at the headwaters of Grey's Creek (GET0005) did not meet the STAC TN threshold and was classified as eutrophic (Figures 4.1.2 and 4.1.3).

St. Martin River

None of the eleven stations met TN or TP seagrass thresholds. Most stations did not meet the STAC TN or TP thresholds and were classified as eutrophic (Figures 4.1.2 and 4.1.3).

Isle of Wight Bay

Stations in the open bay met the TN seagrass threshold. Five stations on Manklin, Turville, and Herring Creeks (MKL0010, TUV0034, TUV0019, TUV0011, and HEC0012) failed the TN seagrass threshold (Figure 4.1.2). No stations were located in the seagrass beds behind Ocean City.

No station met the TP seagrass threshold; one station at the headwater of Turville Creek (TUV0034) did not meet the STAC TP threshold and was considered eutrophic (Figure 4.1.3).

Sinepuxent Bay

All five stations were below the TN seagrass threshold (Figure 4.1.2).

Three stations in the northern part of the bay were above the TP seagrass thresholds, while the two southern stations (ASIS 2 and ASIS 16) met the TP seagrass threshold (Figure 4.1.3).

Newport Bay

All twelve stations except one in the lower bay (ASIS 3) were above the TN seagrass threshold. Trappe, Ayers, Marshall, and upper Newport Creeks (KIT0015, BOB0001, TRC0059, TRC0043, AYR0017, and BMC0011) failed the STAC TN threshold and were classified as eutrophic (Figure 4.1.2).

All stations except one in the lower bay (ASIS 3) were above TP seagrass thresholds. Four stations on Trappe Creek (TRC0043, TRC0059, BOB0001, and KIT0015) failed the STAC TP threshold and were classified as eutrophic (Figure 4.1.3).

Chincoteague Bay

Four northern mainstem stations (XCM1562, XCM0159, XBM5932, and XBM8149) did not meet TN seagrass thresholds, while the other 13 stations on the eastern side of the Bay (behind Assateague) and the Virginia portion of the Bay met TN seagrass thresholds (Figure 4.1.2).

Four stations (ASIS 6, 9, 12, and 14) met the TP seagrass threshold. Mainstem and western shore stations (except ASIS 9 and 14) did not meet TP seagrass thresholds, while Public Landing (ASIS 5), Johnson Bay (ASIS 7), and the site north of Chincoteague Island (ASIS 8) had the highest TP concentrations (Figure 4.1.3).

Trends in nutrient concentration

Overall, there were few significant trends at the ASIS stations in Sinepuxent, Newport, and Chincoteague Bays since sampling began in 1987 (1991 at ASIS stations 4,7,8,12, and 13) (Table 4.1.2). No ASIS stations were present in Isle of Wight Bay, the St. Martin River, or Assawoman Bay. The results of trend analyses are shown in Figures 4.1.4, 4.1.5, and 4.1.6. Descriptions of results by embayment follow (refer to Figure 4.1.1. for stations mentioned in the text):

Table 4.1.2: Medians, Sen slopes, and percentage change (slope as percentage of median by year) for indicators with significant trends. TN and TP medians were recorded in µM concentrations here, but were converted to mg/L for status analysis. Negative slopes indicate an improving trend; positive slopes indicate a declining trend. The algorithm for percent change is: ((slope*n years)/median)*100 (Ebersole et al. 2002).

Station	Segment	Indicator	Median	Slope	N Years	Percent Change
ASIS 2	Sinepuxent	TN	23	-0.918	16	-64
ASIS 2	Sinepuxent	TP	1.33	-0.0602	16	-72
ASIS 3	Newport	TP	1.975	-0.0632	16	-51
ASIS 4	Newport	TP	2.36	-0.078	13	-43
ASIS 5	Chincoteague	TP	1.725	-0.0482	16	-45
ASIS 6	Chincoteague	TP	1.57	-0.0482	16	-49
ASIS 7	Chincoteague	TN	37.15	1.5066	13	53
ASIS 7	Chincoteague	TP	1.645	0.04	13	32
ASIS 8	Chincoteague	TP	1.135	0.0784	13	90
ASIS 12	Chincoteague	TP	1.33	-0.0241	13	-24
ASIS 13	Chincoteague	TP	1.345	-0.0349	13	-34
ASIS 16	Chincoteague	TP	1.35	-0.0468	16	-56
ASIS 18	Chincoteague	TP	1.39	-0.0301	16	-35

Sinepuxent Bay

Improving trends were found at both stations in the southern part of this bay (ASIS 2 and ASIS 16). In the mid-portions of the bay, in the vicinity of the Route 611 Bridge only, TN concentrations exhibited no trend (ASIS 18). No significant trends were found in the northern part of Sinepuxent Bay (ASIS 1 and ASIS 17).

Newport Bay

Both stations in Newport Bay showed significantly improving trends in TP concentration (ASIS 3 and ASIS 4).

Chincoteague Bay

The most noticeable trends in Chincoteague Bay were found in Johnson Bay (ASIS 7). Here both nutrient indicators were significantly degrading. TP was also degrading at Wildcat Point in Virginia north of Chincoteague Island (ASIS 8). On the other hand, TP was significantly improving in the central stations of Chincoteague Bay (ASIS 5 and ASIS 6).

Summary

Upper tributaries of the St. Martin River, Assawoman Bay, Newport Bay, and Isle of Wight Bay were found to be severely nutrient enriched. The mainstem St. Martin River, northern Assawoman Bay and tributaries, and Herring Creek (HEC0012) were also highly enriched. Sinepuxent Bay, southern Chincoteague Bay, and open Isle of Wight Bay had the lowest TN concentrations. Phosphorus enrichment appeared to be more widespread with few stations in the Coastal Bays meeting the seagrass threshold for TP.

Many areas failed seagrass thresholds for TN and TP. One possible explanation is the use of median concentrations based on annual TN and TP and not on seagrass growing season. Another explanation may be that the Coastal Bays system is known to have high dissolved organic nutrients. Higher TN and TP concentrations may result from this, especially when compared to the Choptank River in the Chesapeake Bay system where thresholds were developed (Stevenson et al. 1993). However, studies have shown that TN and TP may be better than dissolved inorganic nutrients as indicators of relative nutrient availability in systems known to have high organic inputs (Glibert et al. 2001). Further research on the applicability of seagrass thresholds in the Coastal Bays is recommended.

Another concern is the route that nutrients take to enter the Coastal Bays. If nutrients are delivered via direct groundwater upwelling, which may be occurring in some areas of the bays (Dillow et al. 2002), they may be sequestered by benthic micro- and macroalgae or macroscopic plant material (e.g., seagrasses) and never enter the sampled water column. Therefore, nutrient concentrations derived from routine water column samples may underestimate the quantity of nutrient entering the Coastal Bays. The relationships between nutrient loading pathways and subsequent biological uptake warrant further study.

Improving trends in nutrients indicators are a good sign. However, Chincoteague Bay, initially thought to be the least impacted of the embayments, had some disturbing status and trend indicators. Degrading TP trends occurred in Johnson Bay (ASIS 7) and Wildcat Point (ASIS 8), and a degrading TN trend was also found in Johnson Bay. These degrading trends should be further investigated.

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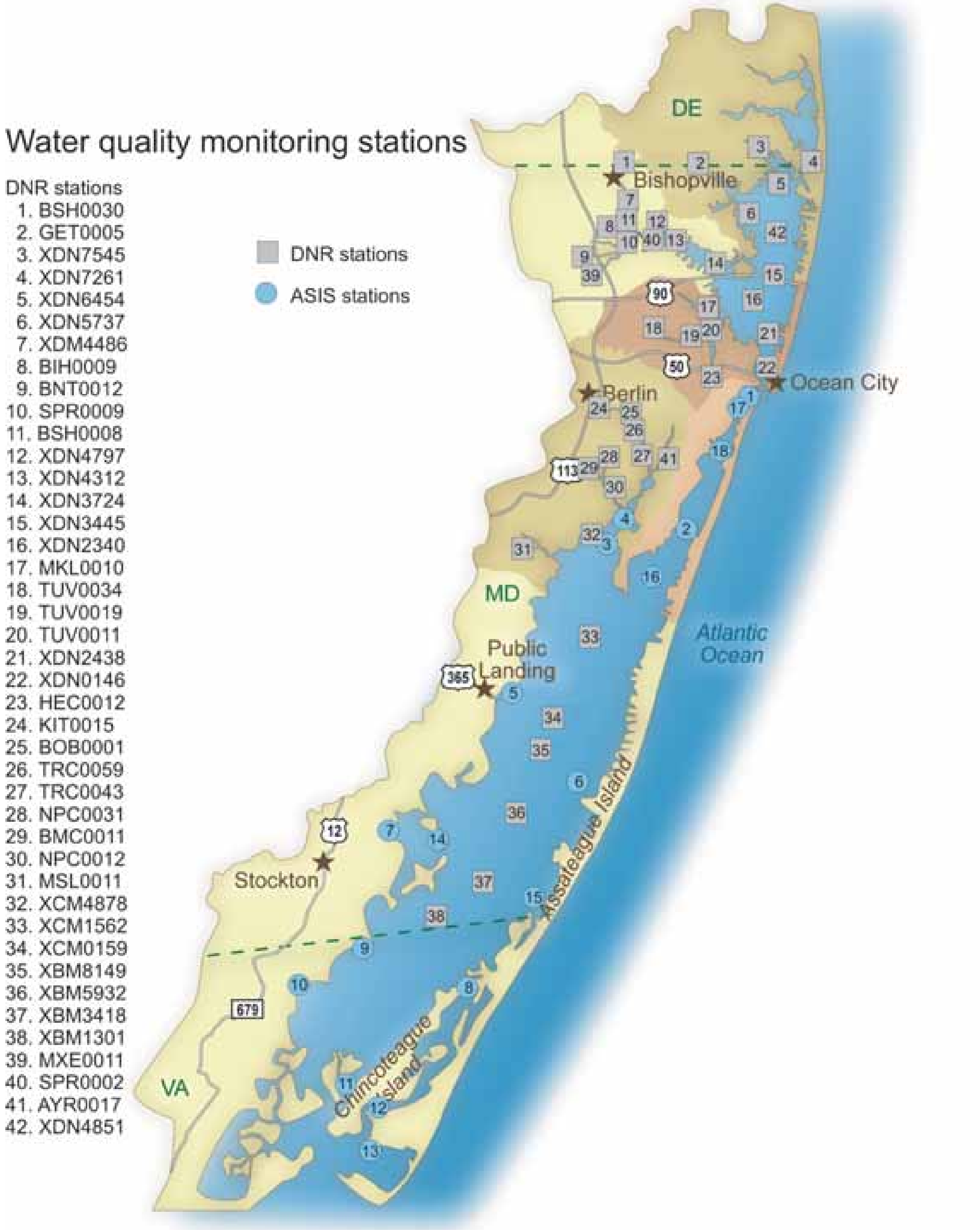

Figure 4.1.1: Map showing water quality monitoring stations for both Maryland Department of Natural Resources (DNR) and the National Park Service, Assateague Island National Seashore (ASIS). DNR stations are listed by DNR code; ASIS stations are referred to as ASIS and the station number (for example, ASIS 1).

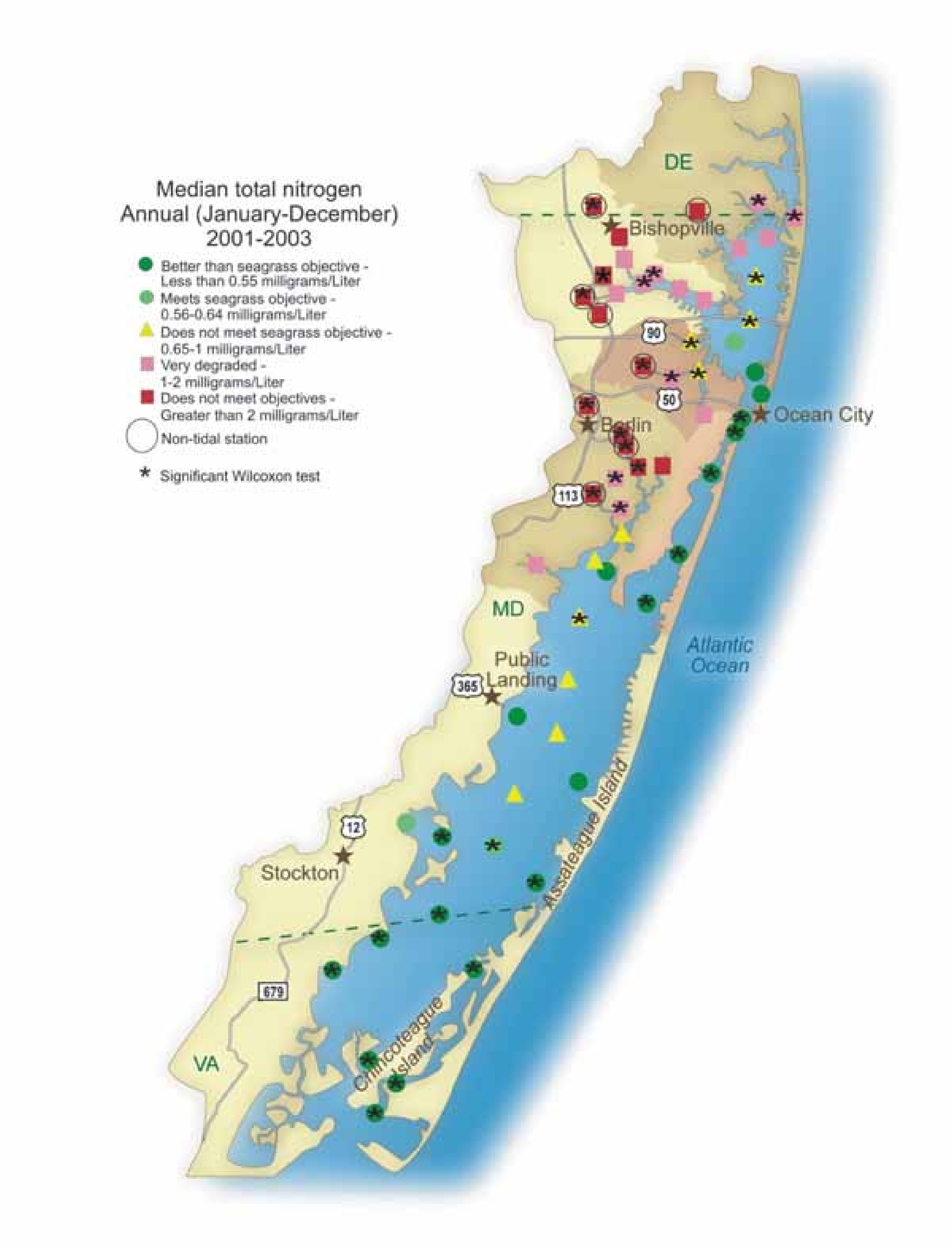

Figure 4.1.2: Median concentrations of total nitrogen in Coastal Bays fixed monitoring stations between 2001 and 2003. Circled stations are non-tidal. Status categories are based on threshold values described in the text.

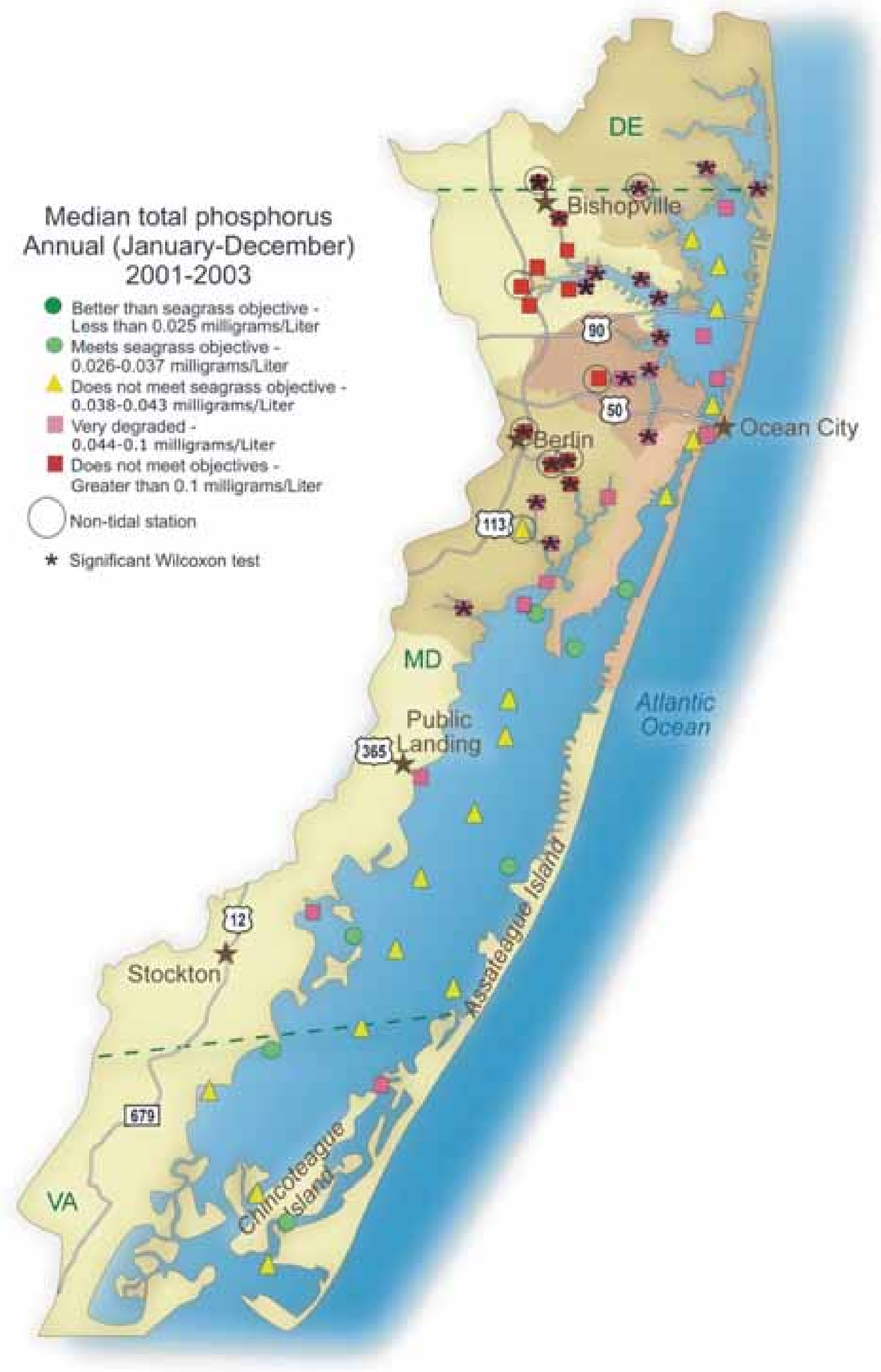

Figure 4.1.3: Median concentrations of total phosphorus in Coastal Bays fixed monitoring stations between 2001 and 2003. Circled stations are non-tidal. Status categories are based on threshold values described in the text.

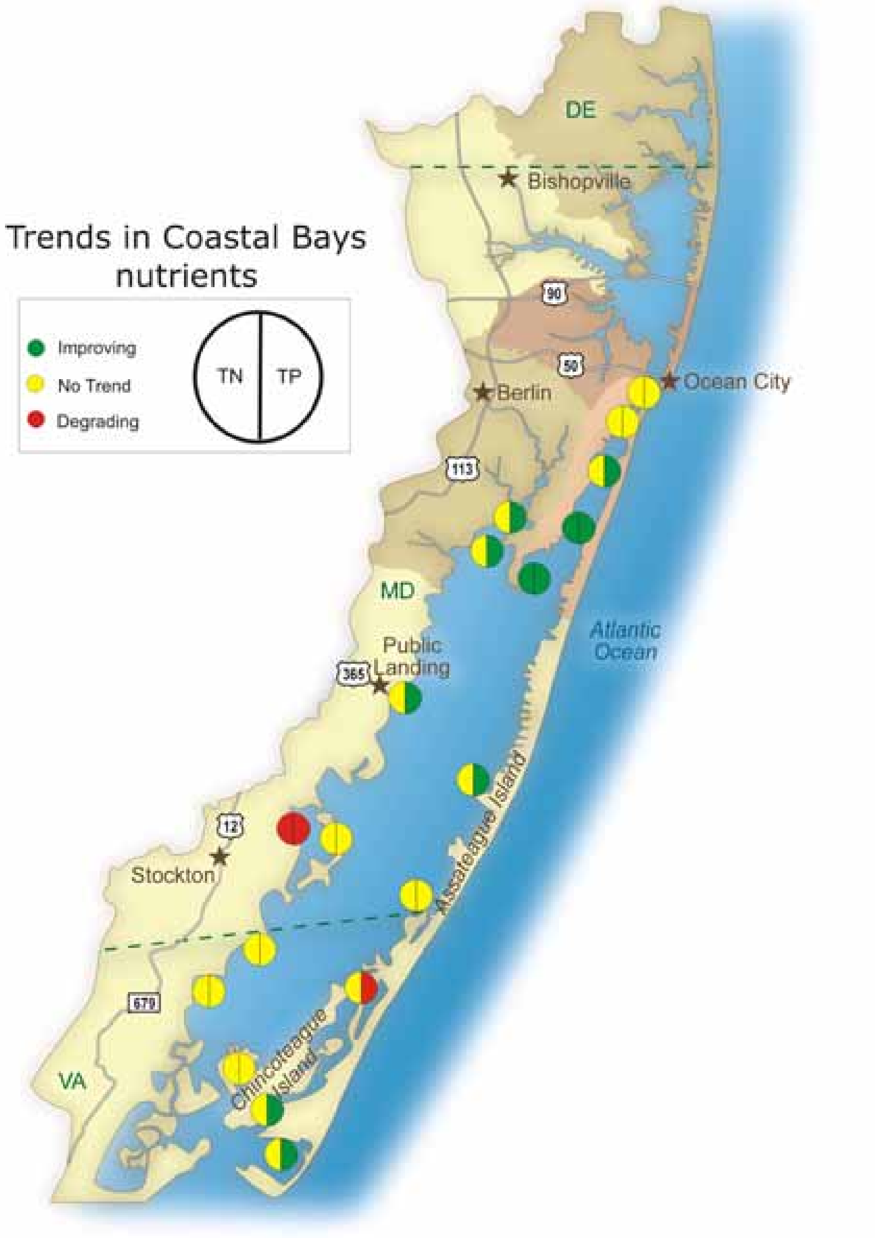

Figure 4.1.4: Nutrient trend analysis of southern Coastal Bays National Park Service fixed water monitoring stations. Trends were based on between 12 and 16 years of data, depending on the station. Significance in trends was calculated using the seasonal Kendall's tau statistic, and directionality (improving or degrading) condition for significant trends was determined by linear regression (p = 0.01).

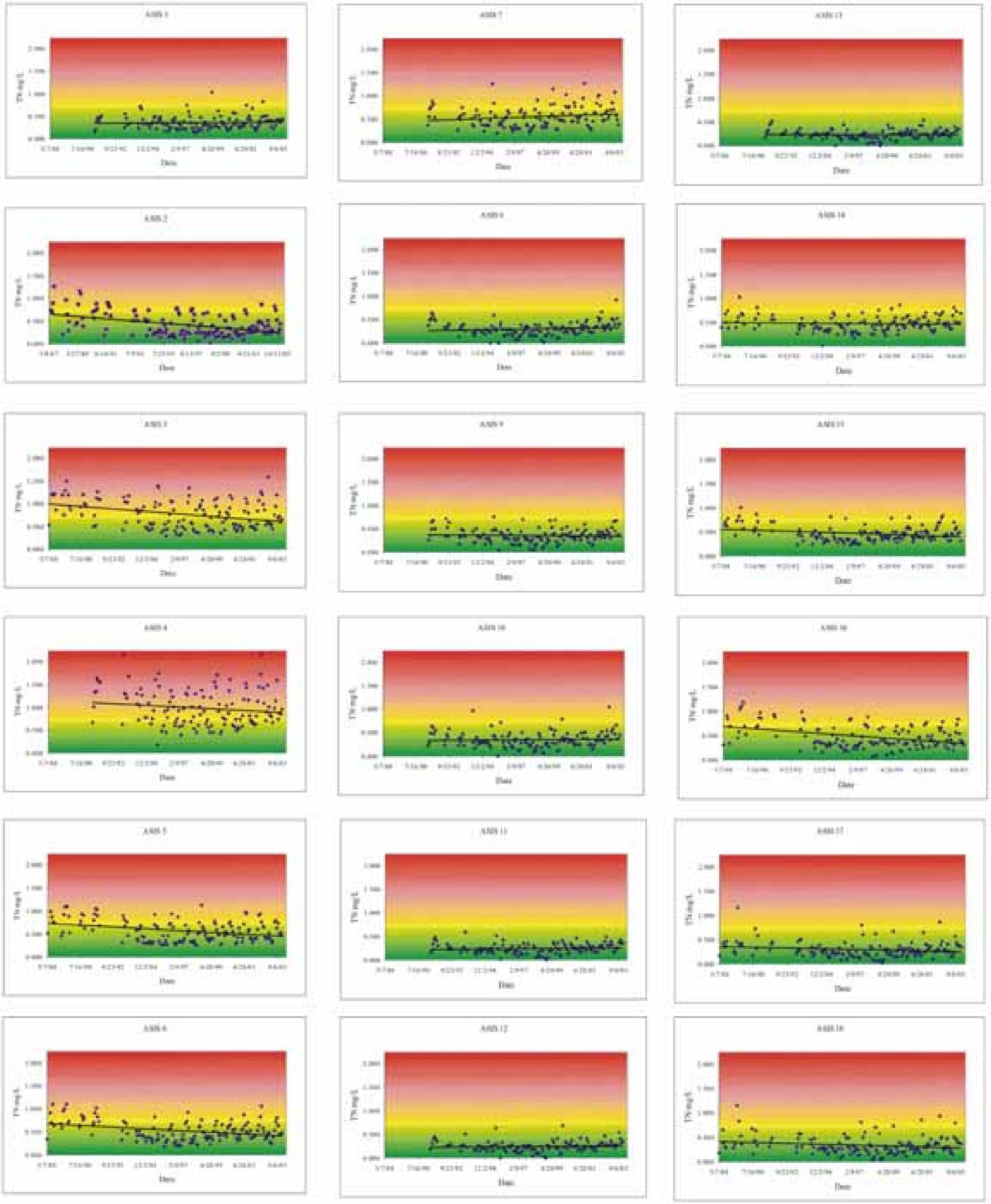

Figure 4.1.5: Total nitrogen trend analysis at ASIS stations. Trend lines indicate directionality; underlying colors indicate status threshold categories (see Figure 4.1.2). Data are monthly medians and are uncensored. Stations 2 and 16 had significant improving trends (decreasing total nitrogen concentration); station 7 had a significantly degrading trend (increasing total nitrogen concentration), despite values remaining mostly within acceptable status threshold levels. Significance was based on the seasonal Kendall tau test (see text).

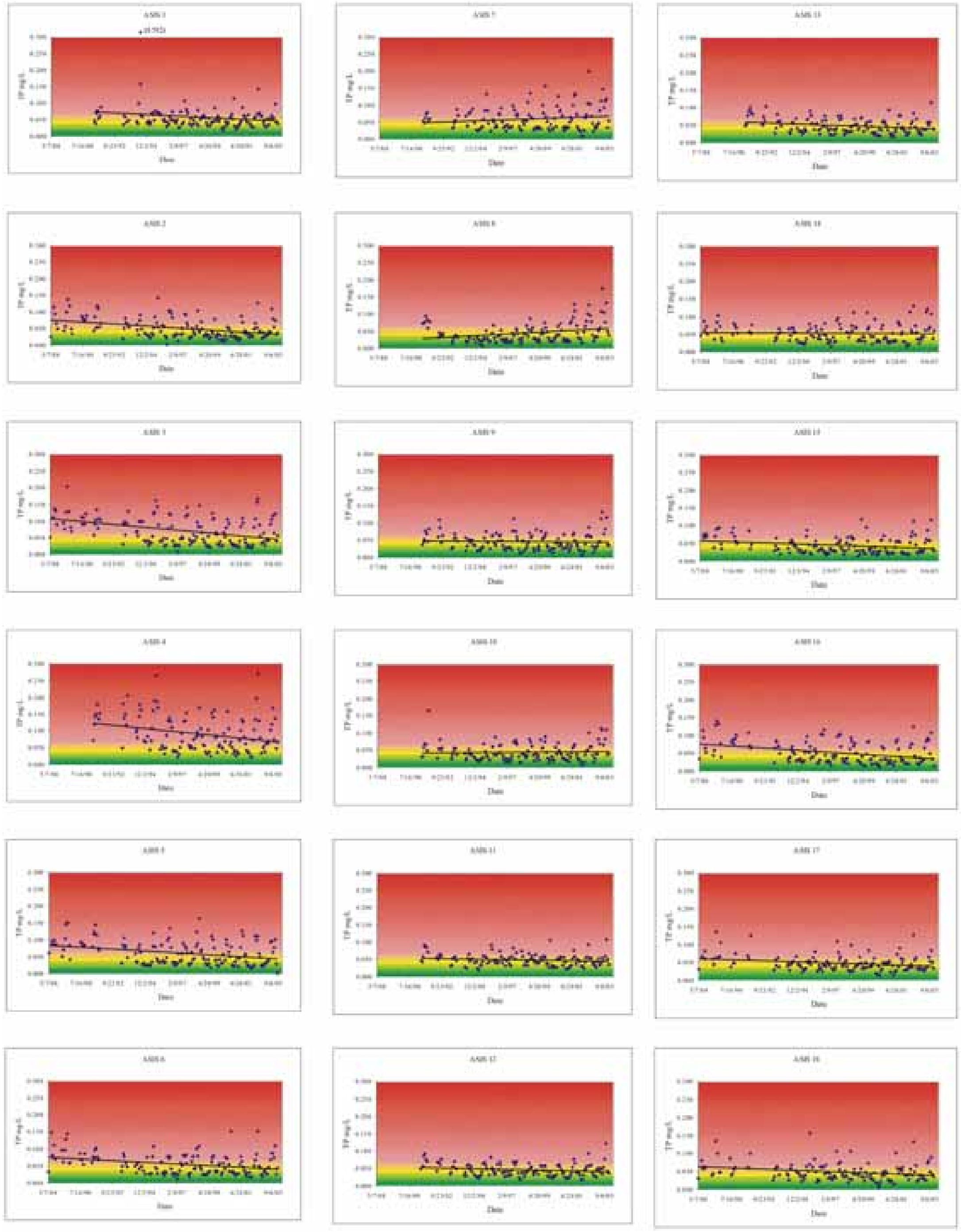

Figure 4.1.6: Total phosphorus trend analysis at ASIS stations. Trend lines indicate directionality; underlying colors indicate status threshold categories (see Figure 4.1.3). Data are monthly medians and are uncensored. Stations 2, 3, 4, 5, 6, 12, 13, 16, and 18 had significant improving trends (decreasing total phosphorus concentration); stations 7 and 8 had significantly degrading trends (increasing total phosphorus concentration). Significance was based on the seasonal Kendall tau test (see text).

Chapter 4.2

Status and trends of phytoplankton abundance in the Maryland Coastal Bays

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Abstract

Planktonic algae are important in coastal ecosystems as producers and, subsequently, as food sources for fish and shellfish. However, high concentrations of planktonic algae can lead to a reduction in water clarity and dissolved oxygen, creating unsuitable conditions for living resources (fish, shellfish, and seagrasses). Planktonic algae were monitored in the Coastal Bays by measuring water column chlorophyll concentrations using fixed station and continuous monitors, as well as intensive spatial mapping. Phytoplankton abundance in the Isle of Wight, Sinepuxent, and Chincoteague Bays were generally low enough to allow for seagrass growth. The St. Martin River and most of Newport Bay demonstrated high chlorophyll levels and failed the thresholds established for seagrass growth. Despite many inshore and river areas failing nutrient thresholds, water column chlorophyll levels were generally low in the open bays but high in those tributaries.

Introduction

Phytoplankton is an important food source to many living resources (shellfish and fish) in the Coastal Bays. However, large algae blooms in the water column can lead to oxygen depletion. High levels of water column algae can also limit the amount of light available to seagrasses.

The concentration of chlorophyll, the green pigment in planktonic algae, is often used to represent the amount of planktonic algae in the water column. Planktonic algae levels are affected by a number of factors including temperature, light, nutrient levels, and grazing by zooplankton and shellfish. Reducing the amount of nutrients entering the bays is expected to reduce chlorophyll levels and improve water clarity and oxygen levels.

Data Sets

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

Department of Natural Resources (DNR) monitored chlorophyll *a* monthly at 28 fixed sites in the St. Martin River and Newport Bay since 1998 and 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 monitors approximately 24 fixed stations. Chlorophyll *a*, along with several other indicators, was measured during this sampling. Samples from these stations were sent to laboratories at the Maryland Department of Health and Mental Hygiene (DNR) or the University of Maryland (ASIS and MCBP) for extractive spectroscopic analysis of chlorophyll *a* concentration.

While monthly sample collections provide important information on patterns of water quality variation, they can often miss events occurring on smaller time scales or during times of the day or year when it is impractical to deploy field personnel. Monthly sampling cannot provide data on the duration of poor water quality events. In order to assess these smaller time scales, DNR has installed two continuous monitors in the northern Coastal Bays (Figure 4.2.1). These monitors measure a suite of water quality parameters every 15 minutes and telemeter the data to a website for near real-time viewing (Maryland Department of Natural Resources 2004). 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. Continuous monitors estimated total chlorophyll *in situ* using a built-in fluorometer. This method cannot discern chlorophyll *a* concentrations, but this is typically the dominant form found in surface water samples. In addition, ASIS conducted temporally intensive surveys in 2003. Field personnel collected chlorophyll samples for extractive laboratory analysis every three hours during three separate ten-day periods in Newport and Chincoteague Bays.

Additionally, DNR, in conjunction with the University of Maryland Center for Environmental Science (UMCES), implemented spatial monitoring between 1999 and 2001 (In-Vitro Fluorescence, IVF) and Water Quality Mapping (DataFlow) in 2003. These methods were employed to provide a more comprehensive spatial analysis of microalgal distribution than can be collected through fixed-station monitoring. Briefly, DataFlow monitoring involved a field crew in a small outboard boat equipped with specialized sensors. These sensors recorded water quality data, including total chlorophyll estimates via fluorometer, on a suite of indicators every three to five seconds as the boat moved along a prescribed track. GPS coordinates were also recorded for each measurement. The paired water quality/GPS data were then used to interpolate chlorophyll concentrations over the entire surface area of the bays. Crews collected data bi-monthly from April through October in all bay segments, though Chincoteague Bay was only partially sampled and was not included in this analysis. Like continuous monitoring, DataFlow instrumentation could only record total chlorophyll concentrations.

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

Fixed stations: A median chlorophyll *a* concentration was determined for the seagrass growing season (March - November) for the three-year period from 2001-2003 for each fixed station monitoring station (Figure 4.2.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed criteria for threshold categories based on living resources indicators (see under Management Objective above). Based on these criteria, threshold categories were determined (Table 4.2.1). Each median value was compared to each cutoff value from Table 4.2.1 by non-parametric Wilcoxon test. Those medians that were significantly different at p=0.01 from the two cutoffs between which they fell were considered statistically significant overall.

Continuous monitoring: Frequency of threshold failure was determined using temporally intensive continuous monitoring data from 2002 and 2003 (Table 4.2.2). Continuous monitoring data were compared to monthly and biweekly lab data (Tables 4.2.4 and 4.2.5).

Spatial Data: DNR/UMCES water quality mapping median concentration of interpolated chlorophyll data. Intense spatial data were also collected for the National Coastal Assessment during 2002 and 2003. GIS- interpolated water quality maps were created using the bi-monthly DataFlow data from 2003. The 15 µg/L threshold was used to assess whether the area met or did not meet conditions for seagrass growth. Comparison of the maps from each sample date showed the movement of algal bloom events in each bay segment (except Chincoteague Bay, which was only partially sampled). Finally, the percent area of each bay segment passing and failing the threshold was determined (Table 4.2.3).

Table 4.2.1: Threshold 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 (is median significantly different in threshold category). Bolded values are living resources and dissolved oxygen indicator values as imposed by STAC (see text above).

Threshold criteria category	**Chlorophyll *a* cutoff values for threshold 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

Table 4.2.2: Summary of florescence/chlorophyll continuous monitoring data for 2002 and 2003 in Bishopville Prong and Turville Creek.

Site	**Indicator and Threshold Level**	**2002 results**	**2003 results**
Bishopville Prong	Chl >50	84%	46%
	Chl >30	94%	68%
	Chl >15	98%	88%
Turville Creek	Chl >50	34%	7%
	Chl >30	70%	36%
	Chl >15	94%	75%

Table 4.2.3: Summary of percent areas failing seagrass chlorophyll thresholds (15 µg/L) during 2003 water quality mapping. The medians were calculated based on interpolated water quality mapping data collected from April through October.

Bay segment	**Percent area failing**
Assawoman Bay	3
St. Martin River	73
Isle of Wight Bay	2
Sinepuxent Bay	0
Newport Bay	96

Status of Algae Abundance

The status of chlorophyll concentrations in each Coastal Bays segment is discussed below. Please review Figure 4.2.1 for place names and station locations.

Assawoman Bay

The five upper bay sites did not meet seagrass thresholds while two stations in the open bay (XDN4851 and XDN3445) did meet the seagrass objective. All stations passed the 50 µg/L threshold (Figure 4.2.2). Chlorophyll thresholds were not applicable to a non-tidal station in upper Grey's Creek (GET0005). Spatially intensive data suggested that the fixed stations probably missed the chlorophyll maximum in this creek.

Spatial monitoring showed more than three percent of Assawoman Bay failed the 15 µg/L threshold in 2003 between April and October. Most of the failing area was in the northern and western parts of the bay (Table 4.2.3 and Figure 4.2.3). Bi-weekly intensive spatial monitoring also showed a small bloom in the early season (May) in Grey's Creek and the area behind northern Ocean City and the Assawoman Ditch (northern passage into Delaware) (Figure 4.2.4). The peak bloom occurred in late July and early August throughout the bay.

St. Martin River

All sites failed the seagrass threshold of 15 µg/L. One Bishopville Prong site (XDM4486) did not pass the 50 µg/L threshold and was therefore considered eutrophic. As with Grey's Creek in Assawoman Bay, the chlorophyll thresholds were not applicable to non-tidal sites on Bishopville and Shingle Landing Prongs (Figure 4.2.2).

The Bishopville Creek continuous monitor showed that total chlorophyll concentrations failed two thresholds 84 and 94 percent of the time (50 and 30 µg/L thresholds respectively) from March through November in 2002 (Table 4.2.2). In 2003, the 50 and 30 µg/L chlorophyll thresholds were exceeded 46 and 68 percent of the time (Table 4.2.2). Table 4.2.4 shows monthly data compared to more temporally intense sampling.

Spatial monitoring results indicated that 73.2 percent of the river area failed the 15 µg/L threshold between April and October in 2003 (Table 4.2.3 and Figure 4.2.5). Bi-weekly intensive spatial monitoring also showed this segment to have two bloom periods in 2003. The first bloom occurred in late April to early May and the second bloom lasted two months, from late July into September. The first blooms coincided with more than 75 percent of the river area failing the seagrass threshold, while the second bloom appeared more intense, with up to 100 percent of the river area failing the threshold (Figure 4.2.6).

Isle of Wight Bay

All fixed stations met or exceeded seagrass thresholds except upper Turville Creek, TUV0019 (Figure 4.2.1). Spatial monitoring data suggest this may be the chlorophyll maximum area for this creek. Sites nearest the inlet had the lowest chlorophyll concentrations (likely influenced by clear water coming in from the ocean). Again, chlorophyll criteria were not applicable to non-tidal sites in the headwaters of Turville Creek.

Continuous monitoring on Turville Creek show the seagrass threshold failed 94 percent of the time from March – November in 2002 (33.8 percent and 70.1 percent for 50 and 30 µg/L thresholds, respectively) and 75 percent in 2003 (7 percent and 36 percent for 50 and 30 µg/L thresholds, respectively) (Table 4.2.2). Table 4.2.5 indicates monthly data underestimate chlorophyll in May, June, and July (compared to more temporally intensive samples).

Spatial monitoring shows two percent bay segment area, in upper Turville Creek, failed the 15 µg/L in 2003 (Table 4.2.3 and Figure 4.2.7). Bi-weekly intensive spatial monitoring showed late July/August to have the peak distribution of areas failing seagrass threshold with up to 60 and 50 percent of the area, respectively (Figure 4.2.8). Turville Creek continually had some areas failing the threshold; however, the July bloom indicates a pulse from St. Martin River made it to the open Isle of Wight Bay as well.

Sinepuxent Bay

All fixed stations exceeded seagrass thresholds (Figure 4.2.2).

Spatial monitoring indicated all areas were less than the 15 µg/L threshold in 2003 (Table 4.2.3 and Figure 4.2.9). Bi-weekly intensive spatial monitoring also shows June to have the peak distribution of area failing the seagrass threshold; however, blooms seem to be more sporadic in this bay and are likely a factor of tidal cycle (Figure 4.2.10).

Newport Bay

Seagrass thresholds were only met at two sites in the lower bay (Not applicable to non-tidal sites on upper of Trappe, Ayer, and Newport Creeks). The Trappe Creek station (TRC0043) was eutrophic and Ayer (AYR0017, MCBP 33) and Marshall Creeks (MSL0011, MCBP 12) were more polluted than other areas (Figure 4.2.2).

Intensive temporal monitoring from a short term study initiated by ASIS in 2003 collected chlorophyll data every three hours during three separate ten day periods. Chlorophyll values were above seagrass threshold levels values 90 percent of the time in June (Figure 4.2.11). During the July/August sampling period, there was more variation between sampling times with all values above seagrass habitat criteria. Approximately 10 percent of samples were above TMDL threshold of 50 µg/L.

Spatial monitoring in Newport Bay shows 96 percent area failed the 15 µg/L threshold in 2003 (Table 4.2.3 and Figure 4.2.12). Bi-weekly intensive spatial monitoring also showed two bloom periods. The first bloom in May/June lasted two months (90 –100 percent of area failing seagrass threshold) and the second in late July/August lasted one month with nearly 100 percent of areas failing seagrass threshold (Figure 4.2.13). Blooms in Newport extend from the upper tributaries throughout bay and often down into Chincoteague Bay. Blooms were most persistent in the tributaries and along the western shore in most months.

Chincoteague Bay

All sites met seagrass thresholds with almost all sites better than seagrass threshold (e.g., less than 7.5 µg/l) (Figure 4.2.2).

Two stations were monitored in 2003 as part of ASIS short-term study in Chincoteague Bay at Public and Taylor Landings. The **Public Landing** site showed 85 percent of chlorophyll values were at or below seagrass habitat thresholds in June (15 µg/L)(Figure 4.2.14). During the final two days of the June deployment at Public Landing, there was a marked increase in chlorophyll concentration. Examination of ancillary data revealed that this was probably due to re-suspension of benthic algae as this occurred during a strong wind event prior to a storm and there was no increase in nutrients before or during the event. These results suggest that benthic micro algae concentrations may be as high or higher than phytoplankton and an important primary producer in this system. The July/August period exhibited higher chlorophyll levels than the earlier June time frame with 90 percent of the values above seagrass thresholds. At **Taylor Landing**, 90 percent of the chlorophyll samples were at or above seagrass habitat criteria during June (Figure 4.2.15). Average chlorophyll levels during July/August were lower overall than the June values with 50 percent of the values being above seagrass threshold levels.

Comparison of Sample Frequency

Table 4.2.4: Comparison of 2002 results from varying temporal frequencies of monitoring in Bishopville Prong. Continuous data were collected every 15 minutes by an *in situ* hydrolab sonde using a fluorescence probe (total chlorophyll) while weekly and monthly data were collected as surface grab samples that were filtered and analyzed by UMD (extractive method for chl *a*). Values presented are means, with standard deviations in parentheses, except monthly data that consisted of a single sample. Periods indicate no or missing data.

Parameter	**Month**	**Continuous Data (t chl)**	**Weekly data (chl *a*)**	**Monthly Data (chl *a*)**
Chlorophyll	June	81.53 (20.48)	100.57 (32.32)	53.83
	July	106.68 (18.45)	93.22 (13.21)	109.10
	August	119.99 (35.27)	111.39 (20.41)	131.60
	September	67.29 (21.46)	52.99 (16.54)	49.34
	October	71.35 (31.66)	42.79 (10.22)	47.10
	November	90.30 (107.55)	.	0.748
	December	22.99 (13.66)	.	5.79
Total Nitrogen	June	.	3.045 (0.25)	2.50
	July	.	3.106 (0.30)	3.420
	August	.	3.643 (0.13)	3.550
	September	.	2.265 (0.36)	2.020
	October	.	2.290 (1.24)	2.020
	November	.	.	6.739
	December	.	.	2.462
Total Phosphorus	June	.	0.270	0.231
	July	.	0.254	0.278
	August	.	0.303	0.313
	September	.	0.151	0.153
	October	.	0.120	0.093
	November	.	.	0.141
	December	.	.	0.086
Salinity	June	23.89	.	23.42
	July	27.02	.	26.23
	August	30.41	.	29.8
	September	25.57	.	24.59
	October	25.71	.	24.91
	November	20.57	.	
	December	22.63	.	20.65

Table 4.2.5: Comparison of 2002 results from varying temporal frequency of monitoring in Turville Creek. Continuous data were collected every 15 minutes by an *in situ* hydrolab sonde using a fluorescence probe (total chlorophyll) while weekly and monthly data were collected as surface grab samples that were filtered and analyzed by UMD (extractive method for chl *a*).Values presented are means, with standard deviations in parentheses, except monthly data which consisted of a single sample. Periods indicate no or missing data.

Parameter	Month	Continuous Data (T chl)	Weekly data (chl *a*)	Monthly Data (chl *a*)
Chlorophyll a	May	72.54	60.8	20.93
	June	58.19	48.17	5.48
	July	48.71	43.27	26.91
	August	51.32	46.00	45.70
	September	30.56	27.60	19.70
	October	24.48	20.98	18.20
	November	26.16	.	25.60
	December	32.37	.	8.40
Total Nitrogen	May	.	1.68	1.34
	June	.	2.64	2.0
	July	.	1.95	2.09
	August	.	2.31	2.25
	September	.	1.59	1.28
	October	.	1.30	1.82
	November	.	.	1.43
	December	.	.	1.10
Total Phosphorus	May	.	0.140	0.110
	June	.	0.178	0.144
	July	.	0.165	0.145
	August	.	0.195	0.156
	September	.	0.010	0.081
	October	.	0.075	0.095
	November	.	.	0.120
	December	.	.	0.048
Salinity	May	23.55	.	26.77
	June	28.57	.	28.03
	July	31.37	.	31.51
	August	33.92	.	32.6
	September	25.79	.	27.79
	October	26.65	.	27.23
	November	19.49	.	6.2
	December	19.15	.	21.95

Trends in algae abundance

Sinepuxent Bay

Improving chlorophyll trends were found in the southern part of the bay while no significant trends were detected in northern areas (Figures 4.2.16 and 4.2.17).

Newport Bay

No significant trends in chlorophyll were present at two sites in the open bay (Figures 4.2.16 and 4.2.17).

Chincoteague Bay

A significantly improving trend in chlorophyll was found at Public Landing (ASIS 5) and a degrading chlorophyll trend was found in Johnson Bay (ASIS 7) (Figures 4.2.16 and 4.2.17). No significant trends were detected at eight other sites in Chincoteague Bay.

Table 4.2.6: Medians, Sen slopes, and percentage change (slope as percentage of median by year) for significant chlorophyll *a* (CHLA) trends. Chlorophyll *a* was recorded in µg/L. Positive slopes indicate a declining trend; negative slopes indicate an improving trend. The algorithm for percent change is: ((slope*n years)/initial median)*100 (Ebersole et al. 2002).

Station	Segment	Indicator	Median	Slope	N Years	Percent Change
ASIS 2	Sinepuxent	CHLA	4.797	-0.2831	16	-95
ASIS 7	Chincoteague	CHLA	5.438	0.3195	13	76
ASIS 16	Chincoteague	CHLA	5.38	-0.03784	16	-11
ASIS 18	Chincoteague	CHLA	4.742	-0.02425	16	-8

Summary

The seagrass chlorophyll threshold was met in Isle of Wight, Sinepuxent and Chincoteague Bays; while the St. Martin River and upper Newport Bay failed. STAC chlorophyll threshold showed eutrophic conditions are present in Bishopville Prong and Trappe Creek.

Intensive temporal monitoring shows the duration of blooms can be very long in these areas. Even Chincoteague Bay showed intense blooms when 90 percent of samples were greater than 15 µg/L at Public Landing in July/Aug and Taylor Landing in June. Recommend continuous monitors be put in all bay segments to better understand duration of blooms.

Spatial monitoring gives better resolution of blooms and shows large scale 'pulses' in some bays. Overall, 24% of the bay area (minus Chincoteague) failed seagrass chlorophyll threshold**.**

Trend analyses show significantly improving trends at 5 out of 18 sites, all in lower Sinepuxent and middle Chincoteague Bays. A single significantly degrading chlorophyll trend was found in Johnson Bay (ASIS 7).

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, benthic 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.

Chlorophyll criteria for Total Maximum Daily Load (TMDL) analyses that have been approved by the EPA for the St. Martin River, Herring and Turville Creeks, Manklin and Greys Creeks, and Newport Bay use a different metric than those reported here for chlorophyll (Maryland Department of the Environment 2002, 2001). The Maryland Department of the Environment, MDE, applies a mean summer (June-September) chlorophyll value and a 50 µg/L threshold in TMDL models. Applying the same dataset used in the analyses above to the MDE model season, a different picture emerges of areas meeting or failing objectives (Figure 4.2.18). This analysis seems to relate better to areas with oxygen problems (see Chapter 4.3).

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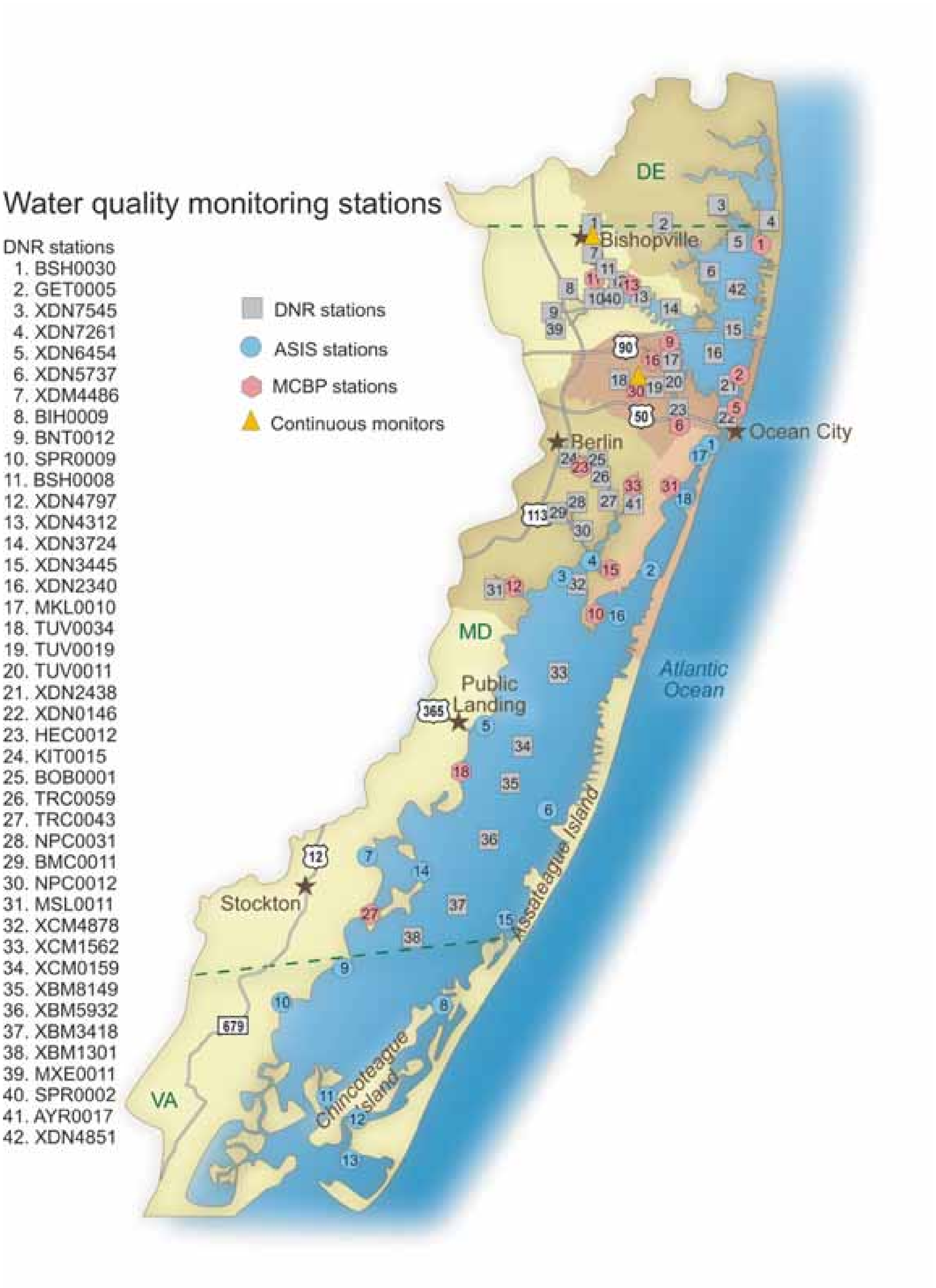


Figure 4.2.1: Map showing water quality monitoring stations for the Maryland Department of Natural Resources (DNR), the National Park Service, Assateague Island National Seashore (ASIS), and the Maryland Coastal Bays Program volunteers (MCBP). DNR stations are listed by DNR code; ASIS and MCBP stations are referred to as ASIS or MCBP and the station number (for example, ASIS 1).

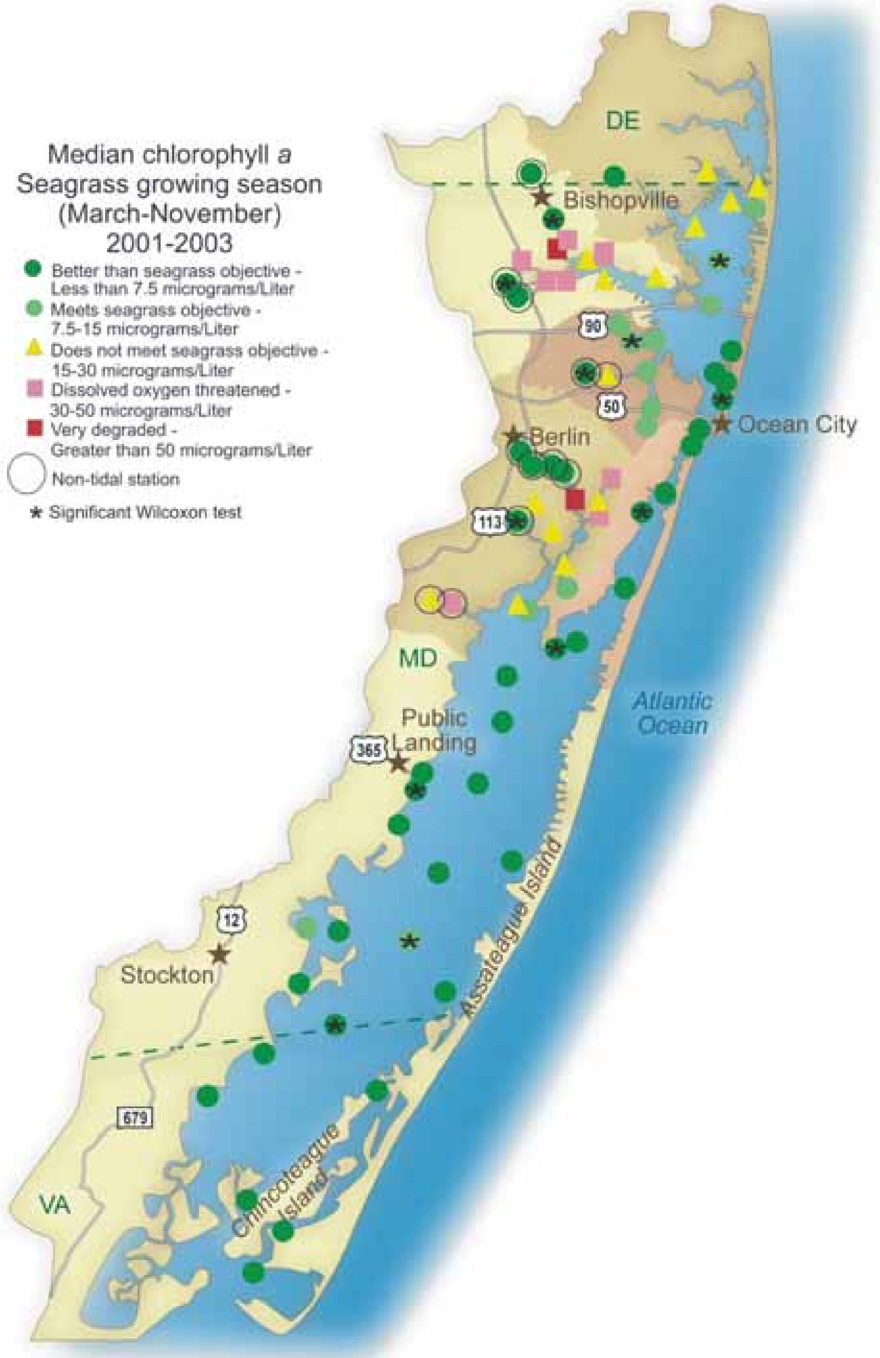


Figure 4.2.2: Median concentrations of chlorophyll *a* in Coastal Bays fixed monitoring stations between 2001 and 2003. Circled stations are non-tidal. Status categories are based on threshold values described in the text.

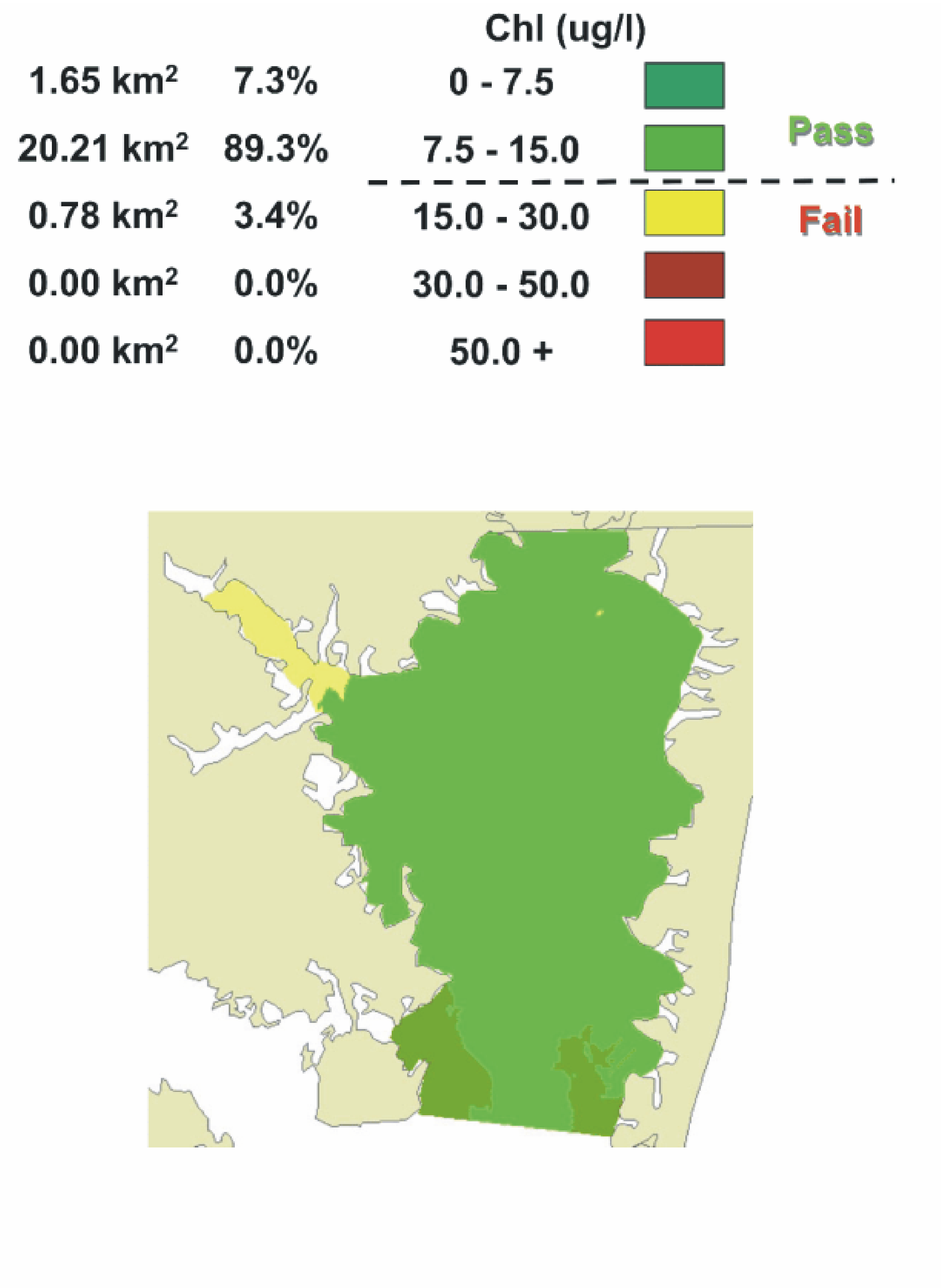


Figure 4.2.3: 2003 DataFlow chlorophyll median results for Assawoman Bay.

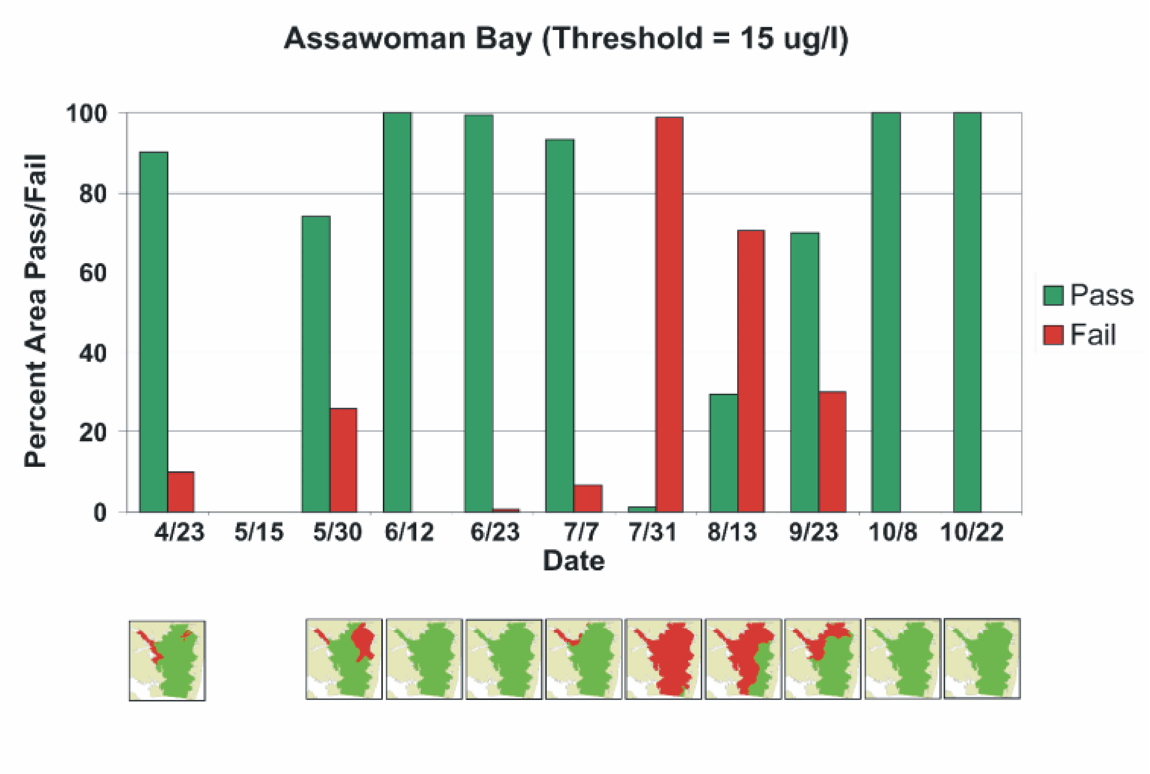


Figure 4.2.4: 2003 DataFlow bi-weekly chlorophyll in Assawoman Bay.

		Chl (ug/l)		
0.0 km²	0.0%	0 - 7.5	🟩	
1.71 km²	26.8%	7.5 - 15.0	🟩	Pass
3.95 km²	62.0%	15.0 - 30.0	🟨	Fail
0.64 km²	10.0%	30.0 - 50.0	🟫	
0.08 km²	1.2%	50.0 +	🟥	

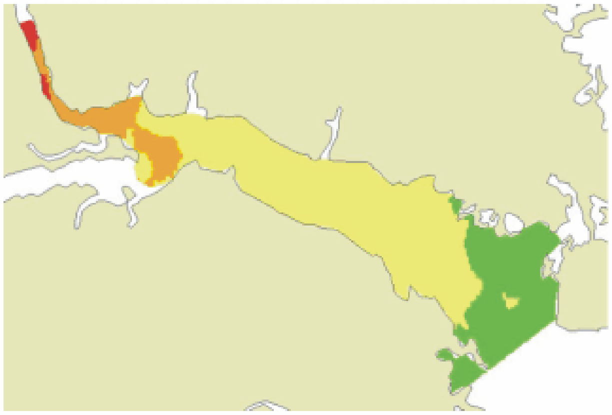


Figure 4.2.5: 2003 DataFlow chlorophyll median results for St. Martin River.

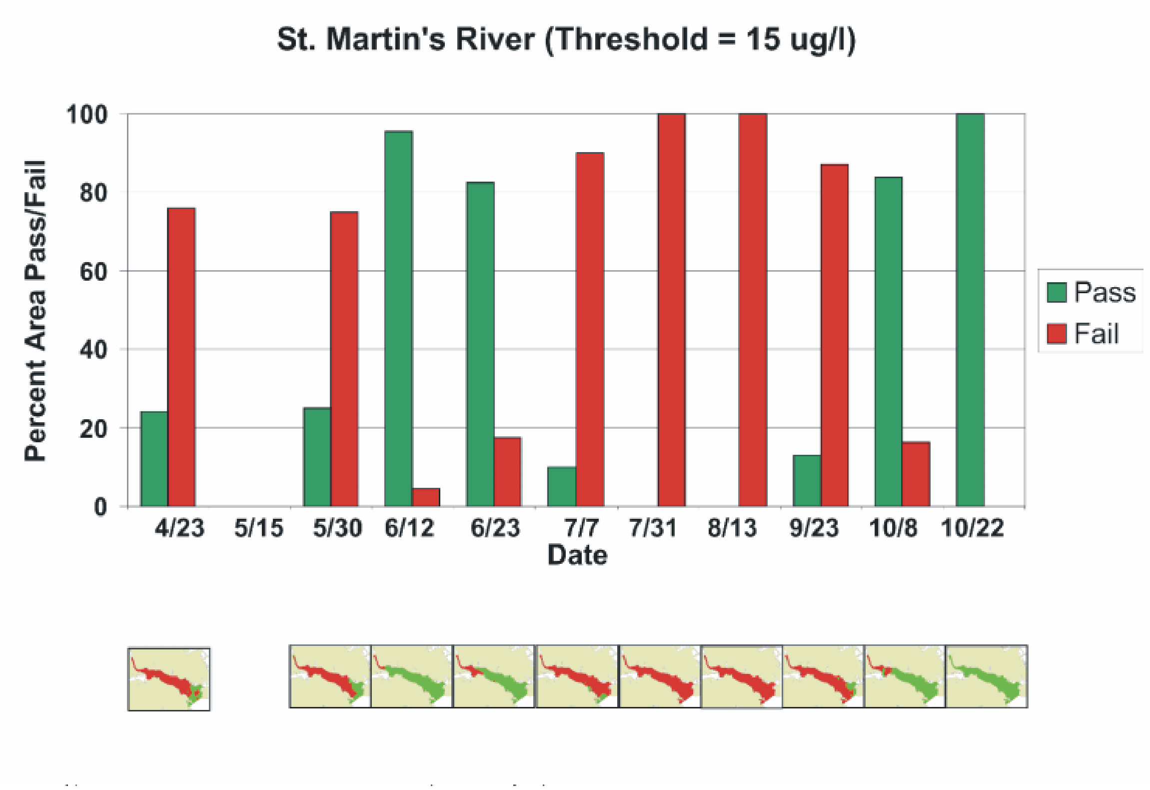


Figure 4.2.6: 2003 DataFlow bi-weekly chlorophyll in St. Martin River.

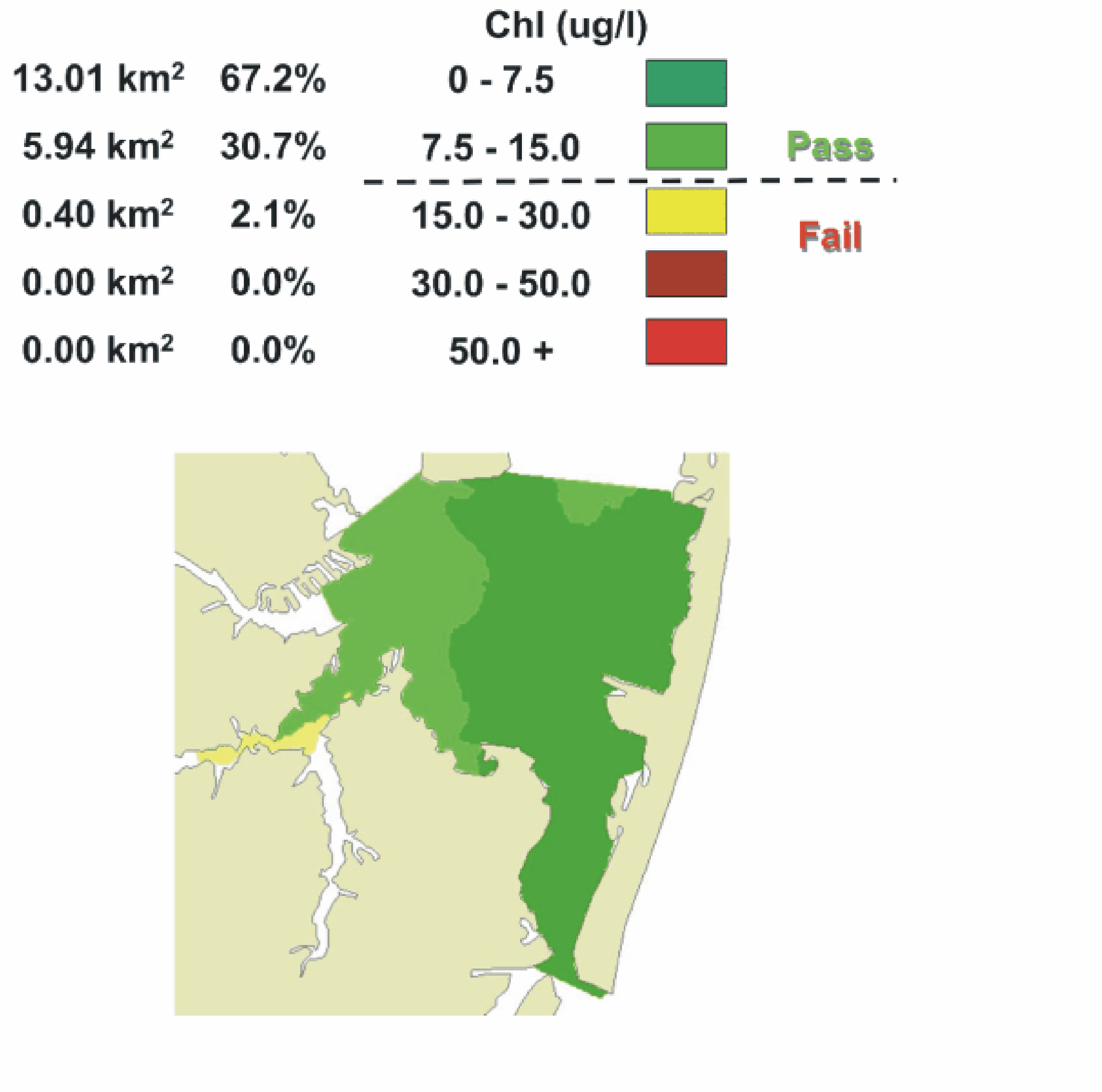


Figure 4.2.7: 2003 DataFlow chlorophyll median results for Isle of Wight Bay.

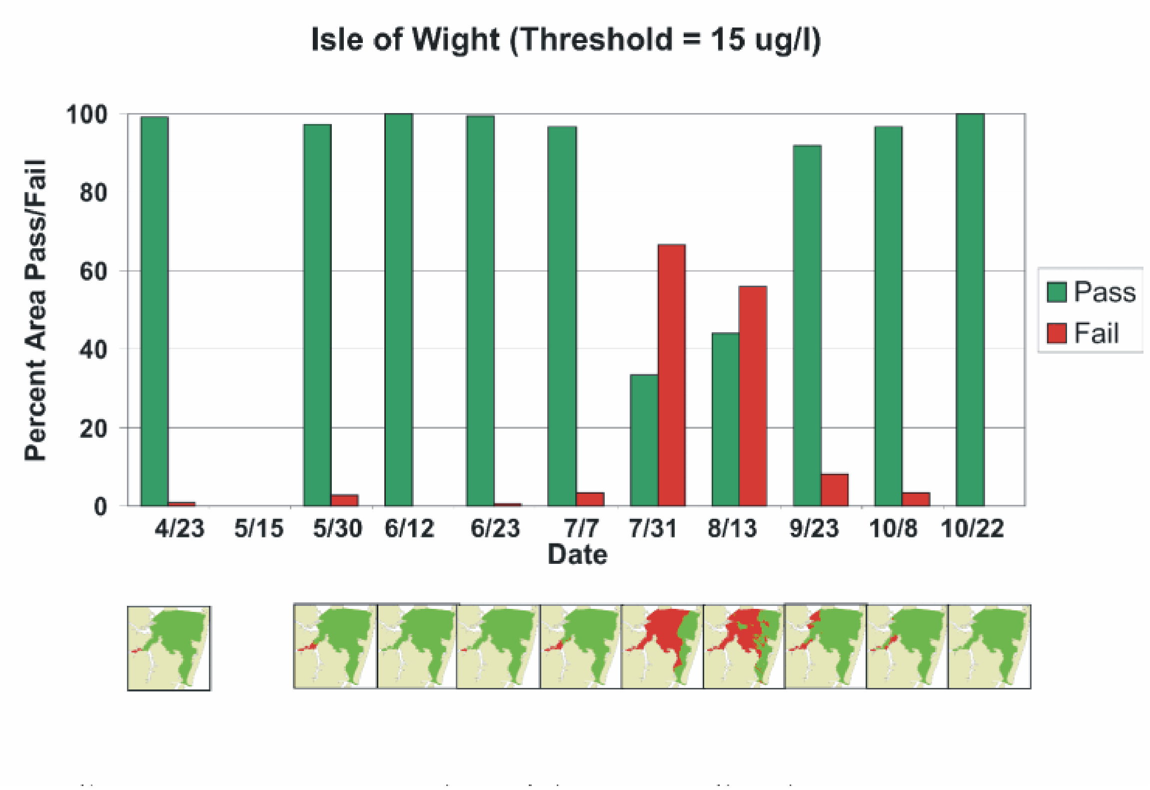
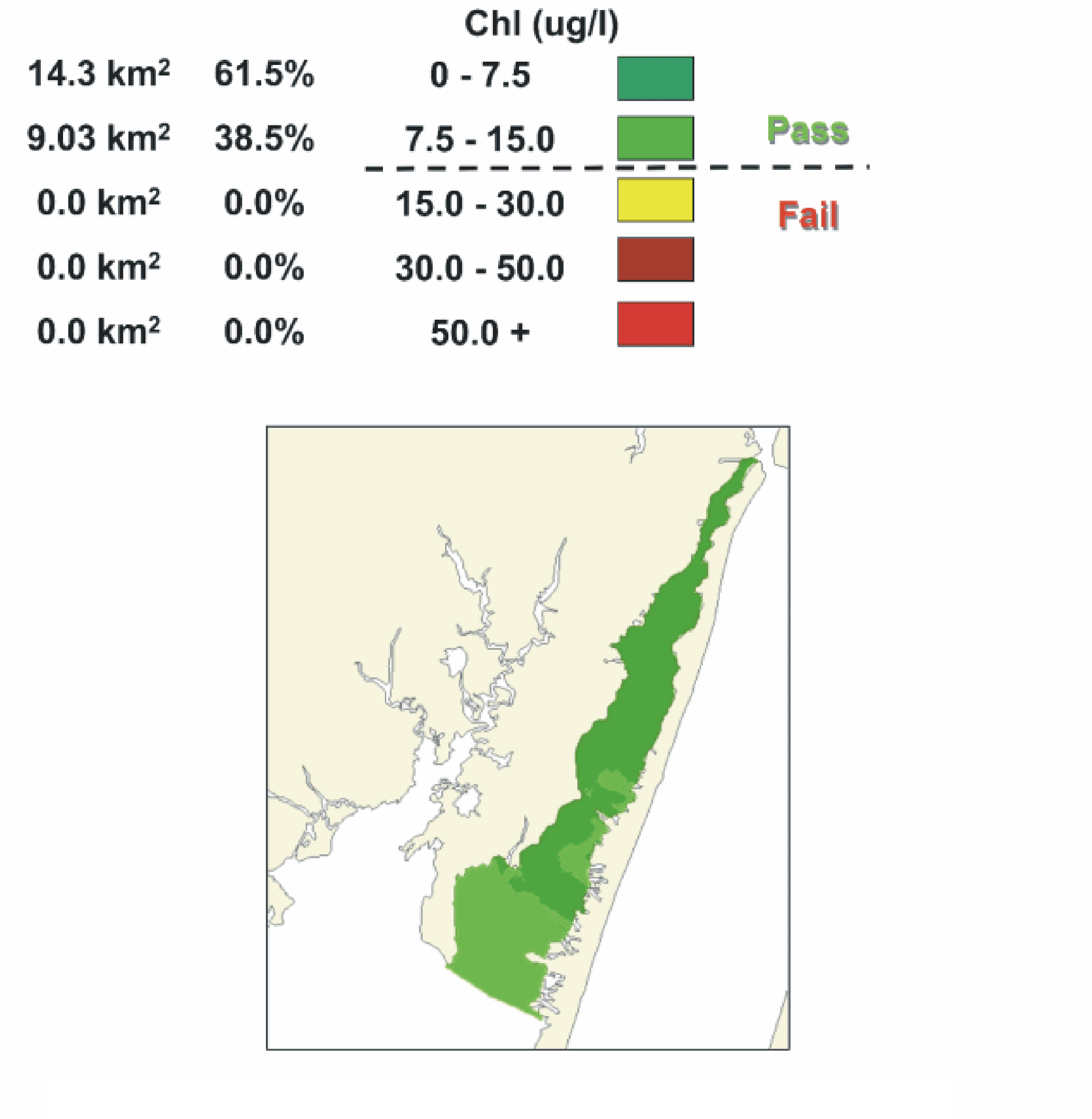


Figure 4.2.8: 2003 DataFlow bi-weekly chlorophyll in Isle of Wight Bay.



		Chl (ug/l)		
14.3 km²	61.5%	0 - 7.5	🟩	
9.03 km²	38.5%	7.5 - 15.0	🟩	Pass
0.0 km²	0.0%	15.0 - 30.0	🟨	Fail
0.0 km²	0.0%	30.0 - 50.0	🟫	
0.0 km²	0.0%	50.0 +	🟥	

Figure 4.2.9: 2003 DataFlow chlorophyll median results for Sinepuxent Bay.

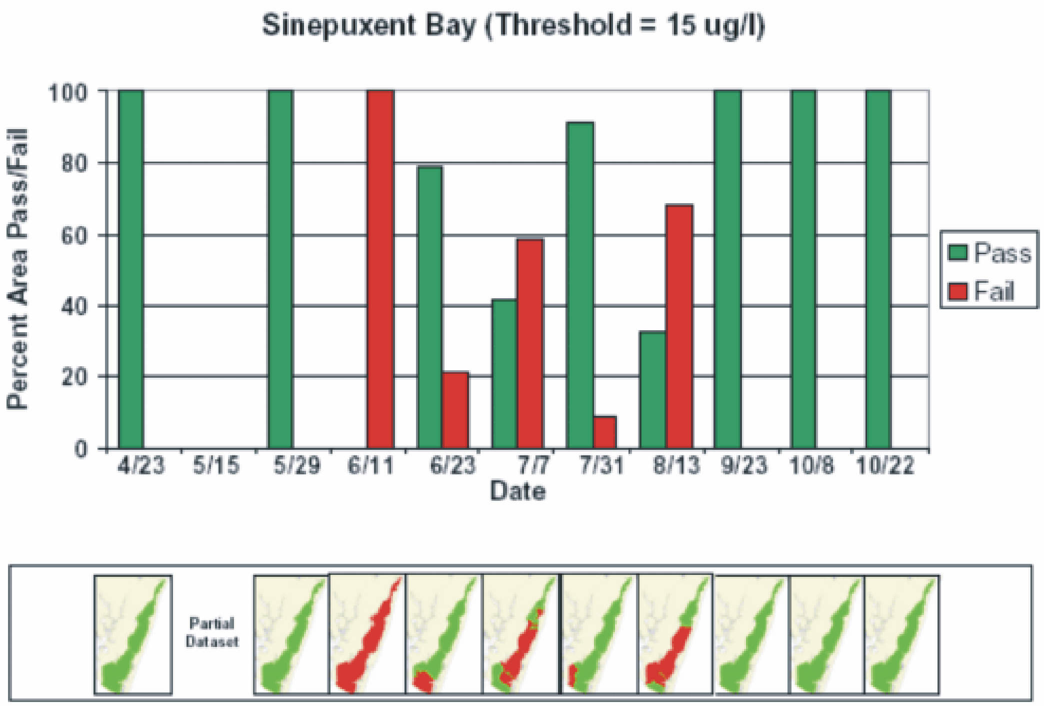


Figure 4.2.10: 2003 DataFlow bi-weekly chlorophyll in Sinepuxent Bay.

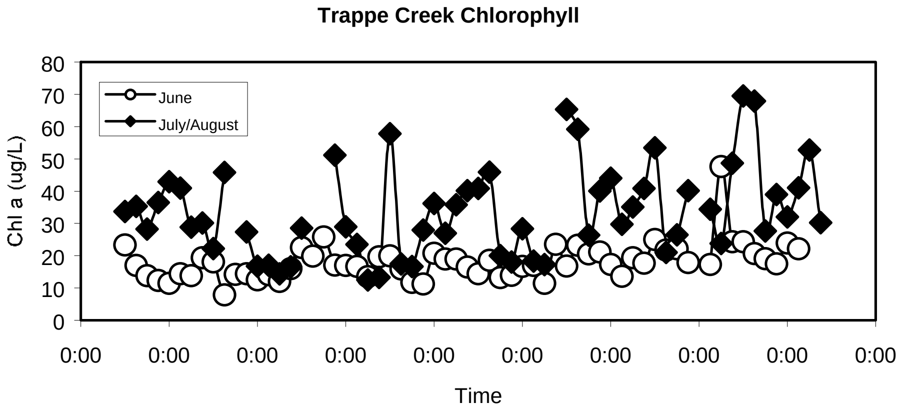


Figure 4.2.11: Chlorophyll *a* concentrations (extractive method) recorded during intensive sampling by Assateague Island National Seashore (ASIS) personnel. Samples were collected every three hours during two separate nine-day periods in Trappe Creek, a tributary of Newport Bay. The times on the x-axis represent midnight of alternative days, or the transition between consecutive two-day periods. Sample dates were June 10 through June 18, 2003 and July 29 through August 6, 2003.

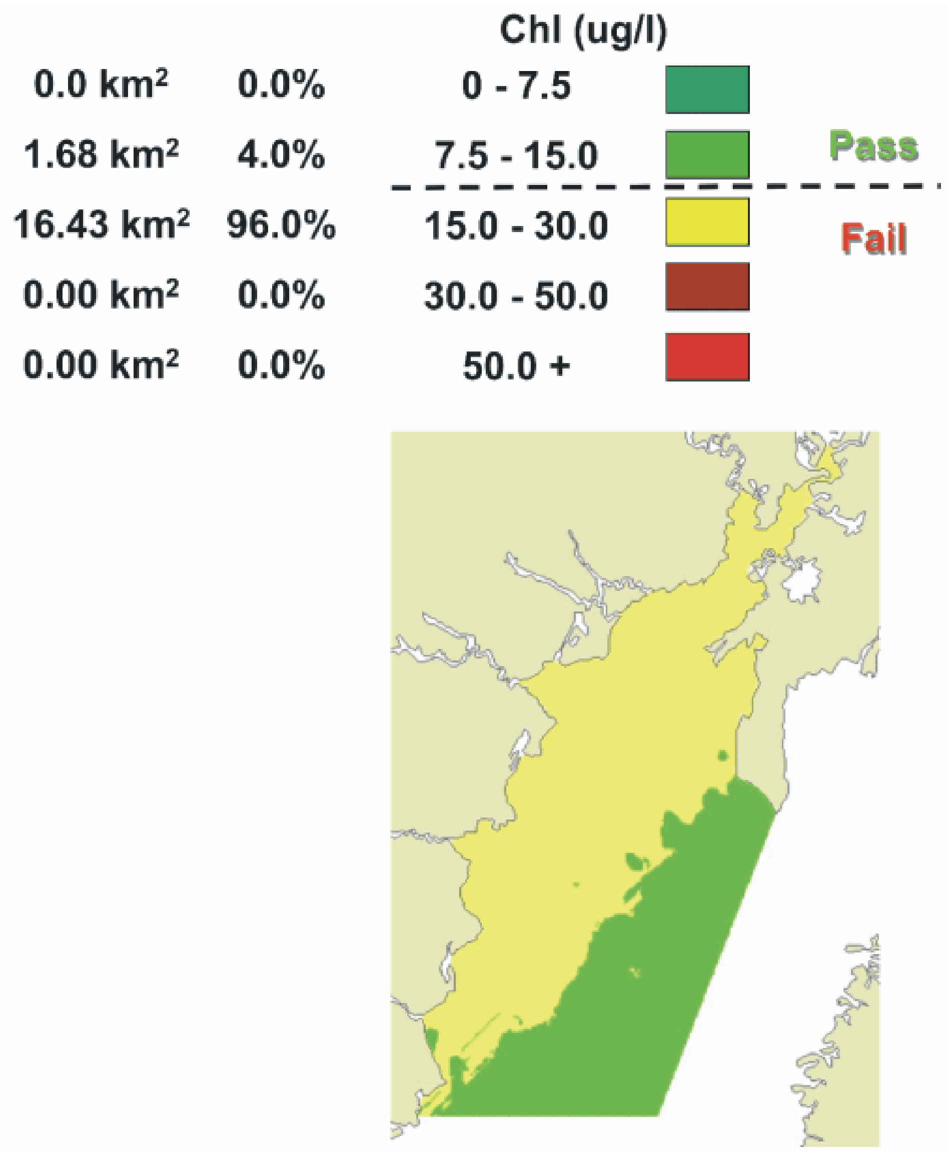


Figure 4.2.12: 2003 DataFlow chlorophyll median results for Newport Bay.

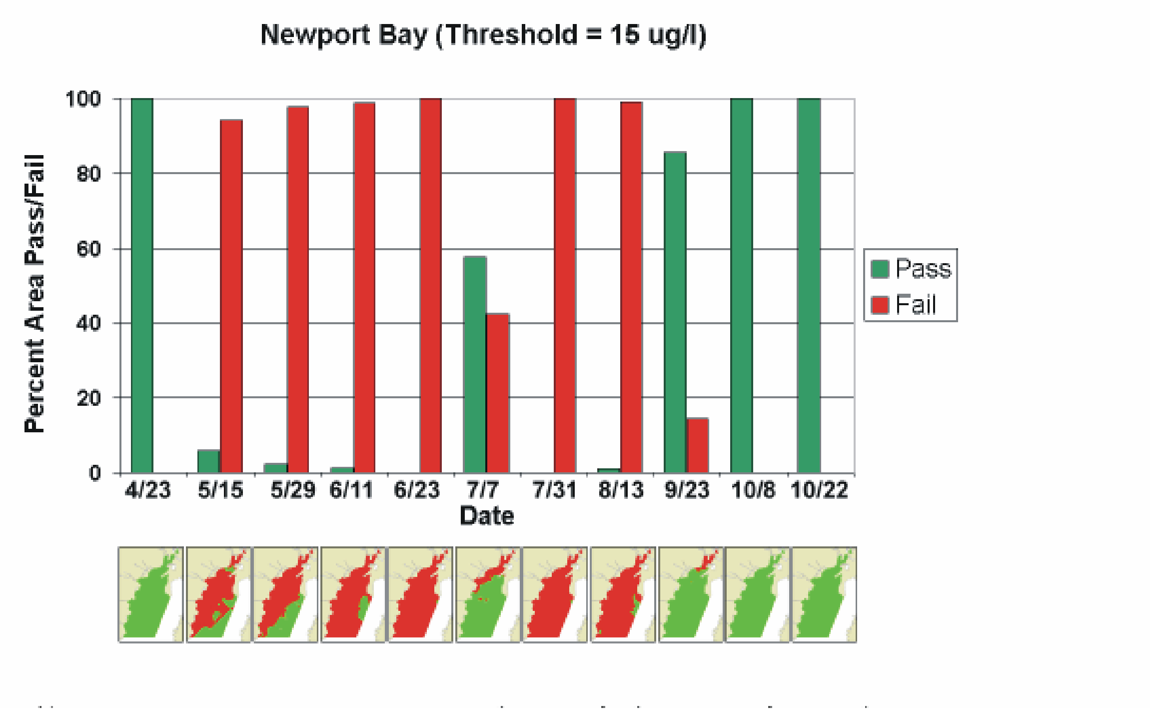


Figure 4.2.13: 2003 DataFlow bi-weekly chlorophyll in Newport Bay.

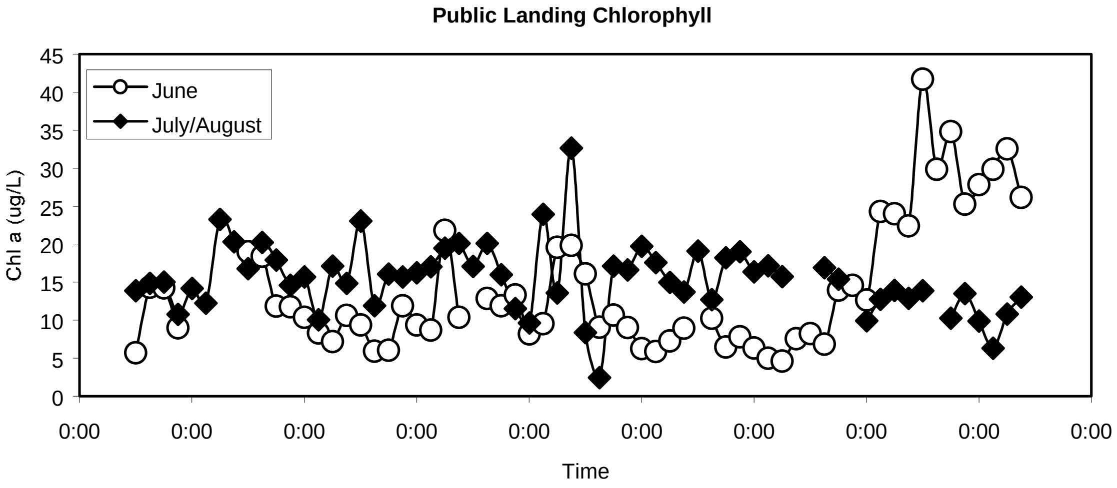


Figure 4.2.14: Chlorophyll *a* concentrations (extractive method) recorded during intensive sampling by Assateague Island National Seashore (ASIS) personnel. Samples were collected every three hours during two separate nine-day periods at Public Landing in northern Chincoteague Bay. The times on the x-axis represent midnight of alternative days, or the transition between consecutive two-day periods. Sample dates were June 10 through June 18, 2003 and July 29 through August 6, 2003.

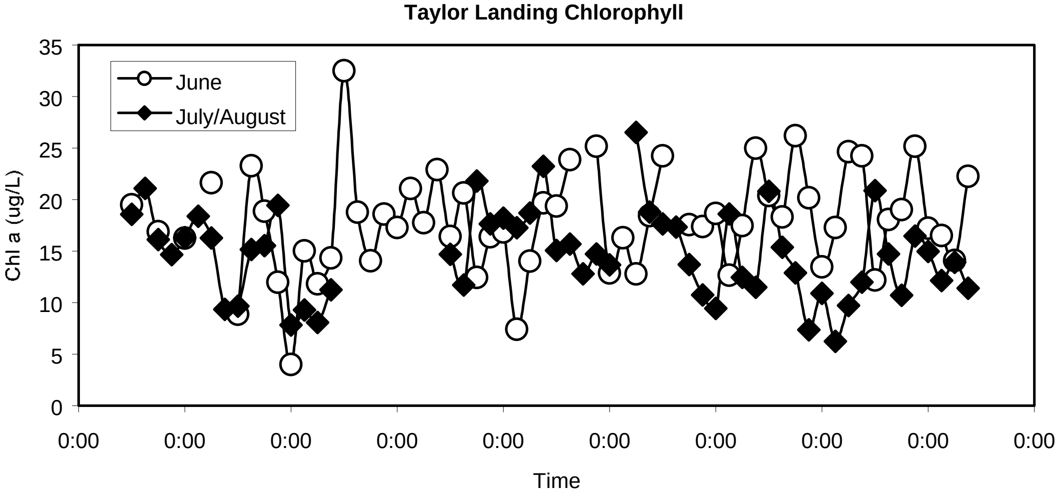


Figure 4.2.15: Chlorophyll *a* concentrations (extractive method) recorded during intensive sampling by Assateague Island National Seashore (ASIS) personnel. Samples were collected every three hours during two separate nine-day periods at Public Landing in northern Chincoteague Bay. The times on the x-axis represent midnight of alternative days, or the transition between consecutive two-day periods. Sample dates were June 10 through June 18, 2003 and July 29 through August 6, 2003.

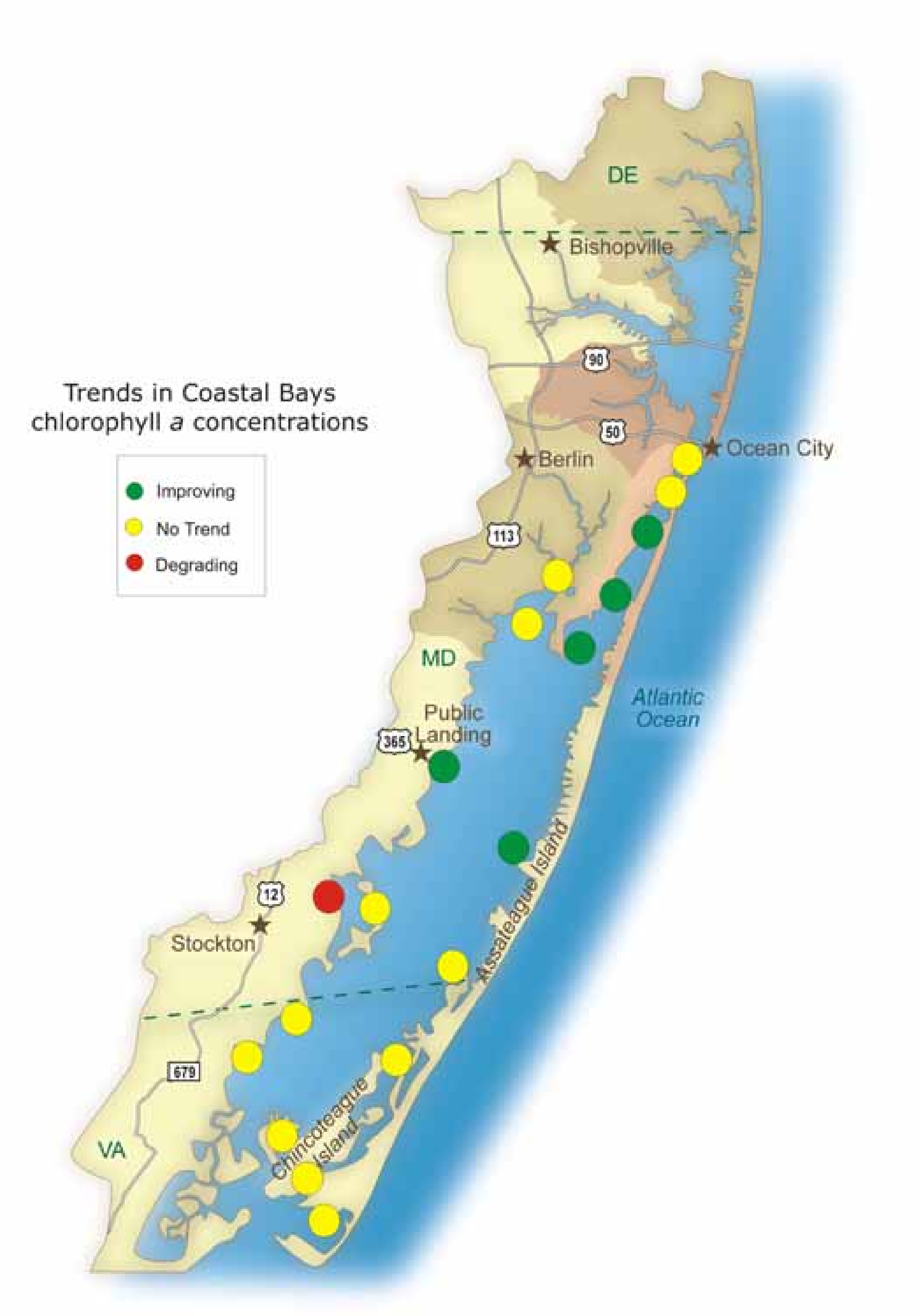


Figure 4.2.16: Chlorophyll *a* trend analysis of southern Coastal Bays National Park Service fixed water monitoring stations. Trends are based on between 12 and 16 years of data, depending on the station. Significance in trends was calculated using the seasonal Kendall's tau statistic and directionality (improving or degrading) condition for significant trends was determined by linear regression (p=0.01).

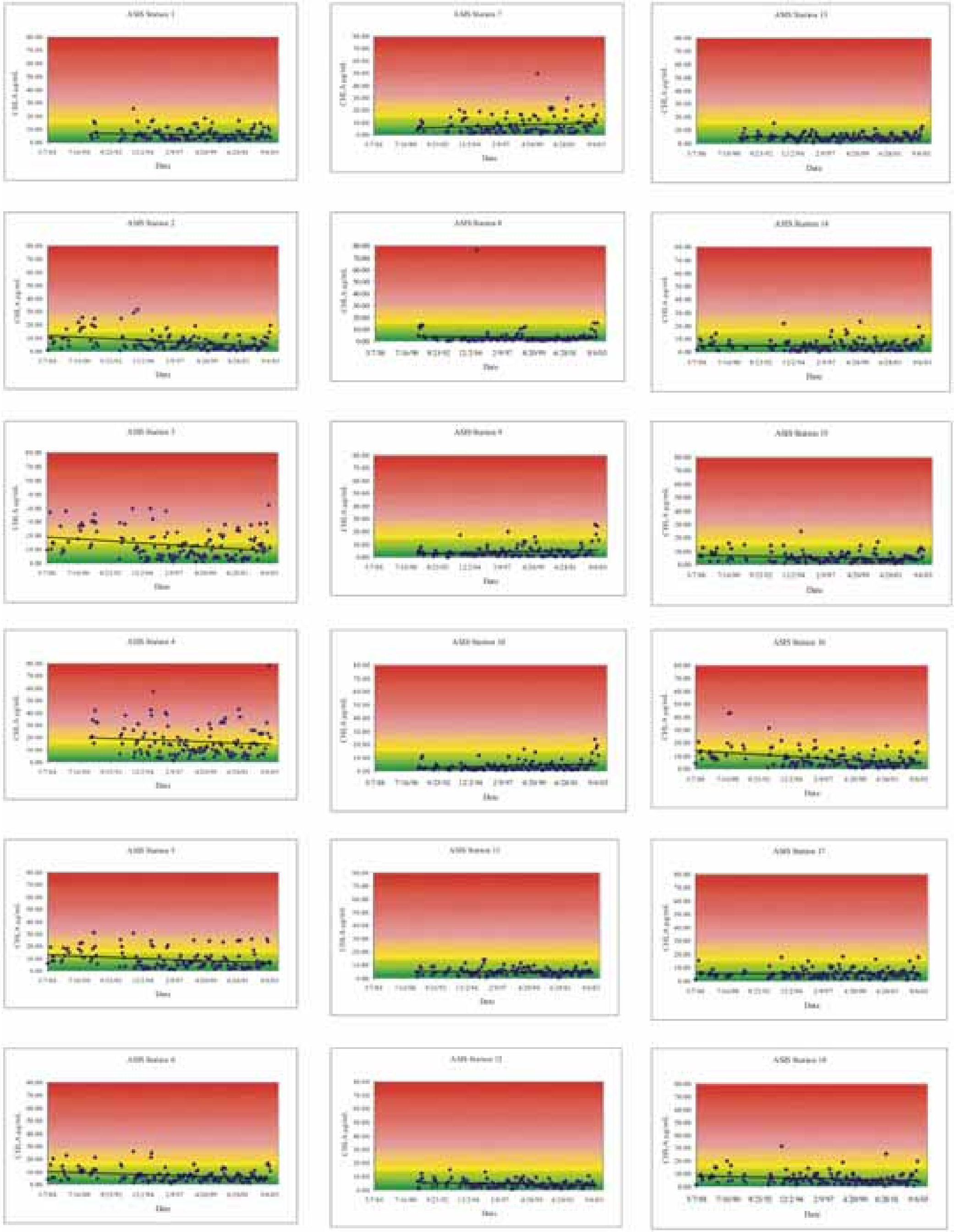


Figure 4.2.17: Chlorophyll *a* trend analysis at ASIS stations. Trend lines indicate directionality; underlying colors indicate status threshold categories (see Figure 4.2.2). Data are monthly medians and are uncensored. Stations 2, 5, 6, 16, and 18 all had significant improving trends (decreasing chlorophyll); station 7 had a significantly degrading trend (increasing chlorophyll), despite values remaining mostly within acceptable status threshold levels. Significance was based on the seasonal Kendall tau test (see text).

Figure 4.2.18: Mean summer (June-September) concentrations of Chlorophyll *a* in Coastal Bays fixed monitoring stations between 2001 and 2003. Circled stations are non-tidal. Status categories are based on threshold values described in the text. This analysis is analogous to those conducted in the determination of TMDLs for Newport Bay and the St. Martin River. TMDL status categories were matched to STAC threshold values (see Figure 4.2.2); hence the duplicate "Meets TMDL goal" categories.

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, dissolved oxygen (DO) concentrations were frequently low in some areas. Daytime measurements showed DO less than 5 mg/L during the summer throughout the St. Martin River and areas of Newport Bay, as well as in Manklin Creek, Herring Creek, Turville Creek, and areas of Chincoteague Bay. Diel data showed DO less than 5 mg/L frequently in tributaries (40-60 percent of the time), but less often in the open bays.

Introduction

Dissolved oxygen (DO) concentration in water is often used to gauge the overall health of the aquatic environment. Oxygen is needed to maintain suitable fisheries habitat. When excessive amounts of algae die and sink to the bottom, bacteria decompose the material and consume oxygen. Dissolved oxygen concentrations near the bottom are often lowest. The low levels of DO that result can impair the feeding, growth, and reproduction of aquatic life in the bays. Organisms that cannot move about easily may die. Fish and crabs generally detect and avoid areas with low DO. Oxygen concentrations that are avoided (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. Since the Coastal Bays are shallow and generally well-mixed bays, low DO does not typically persist for long periods of time and cannot generally be measured by daytime measurements alone. Also, exceedingly high daytime DO levels often surpass threshold levels and then crash at night. 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 do not collect samples until between 9 am and 2 pm. 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 the abundance of benthic algae. Some areas are also suspected to have high sediment oxygen demand.

Maryland state water quality criteria require a minimum DO concentration of 5 mg/L at all times (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*) (Funderburk *et al.* 1991). Blue crabs (*Callinectes sapidus*), bay anchovies (*Anchoa mitchelli*), and 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 levels at fixed sampling stations were monitored monthly during the day by the Maryland Department of Natural Resources (DNR) and the National Park Service, Assateague Island National Seashore (ASIS). Diel oxygen measurements were also made by DNR and ASIS, including a DNR pilot study in 2001 using short deployments (five to seven days) with continuous monitors. Two DNR continuous monitoring sites (one on Bishopville Prong and one on Turville Creek) have been operational since 2002, and two ASIS intensive diel surveys (10 days) at three sites (Trappe Creek, Public Landing, and Taylor Landing) were conducted in 2003. QA issues with NPS continuous monitoring data did not allow analyses of diel data from the three tide gage sites.

Intensive spatial monitoring was conducted through the following projects: seasonal macroalgae monitoring in 2002 and 2003 and the National Coastal Assessment intensive August surveys in 2002 (>100 sites) and 2003 (154 sites) (data not included). Additionally, DO was measured using DataFlow in 2003 throughout the bays (except most of Chincoteague Bay); however, these data were collected in surface water only.

Trends were not determined for DO due to the temporal variability of sample collection (time of day measurements taken were not consistent across sampling programs).

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

Fixed Monitoring Data: A median dissolved oxygen concentration was determined for the summer season (July, August, and September) for the three year period from 2001-2003 for each fixed station monitoring station (Figure 4.3.1). The Maryland Coastal Bays Scientific and Technical Advisory Committee (STAC) developed criteria for threshold categories based on living resources indicators. Based on these criteria, threshold categories were determined (Table 4.3.1). Each median value was compared to each cutoff value from Table 4.3.1 by non-parametric Wilcoxon test. Those medians that were significantly different at p=0.01 from the two cutoffs between which they fell were considered statistically significant overall.

Data were also analyzed for instantaneous minimum oxygen observations between 2001 and 2003. Values at or below 3 mg/L were considered to be detrimental to living resources.

Continuous Monitoring Data: Dissolved oxygen concentrations from two DNR continuous monitors for the years 2002, and 2003 were analyzed for the percent time the concentrations fell below the 5 and 3 mg/L thresholds.

Spatially Monitoring Data: DataFlow data were not included here because methods to temporally standardize the data to daily minimums are currently under development and review. Summer DO from intensive spatial macroalgae sampling in 2001 is presented here in lieu of a DataFlow analysis.

Table 4.3.1: Threshold category values for dissolved oxygen concentration in the Maryland Coastal Bays. Threshold cutoff values are shown. Bolded values are living resources and dissolved oxygen indicator values as suggested by STAC (see text above).

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

Status of dissolved oxygen

The status of dissolved oxygen by Coastal Bays segment is given below. Please view Figure 4.2.1 for place names and stations listed in text.

Table 4.3.2: Summary of summer dissolved oxygen (June – September) from continuous monitoring data collected in Bishopville Prong and Turville Creek during 2002 and 2003. The percent of time threshold levels were not met was calculated from data collected between June to December in 2002 and 2003 results were calculated from data collected between March 26 and November 30.

Site	Indicator and Threshold Level	2002 results	2003 results
Bishopville Prong	DO < 5	59.%	66%
	DO < 3	30%	47%
Turville Creek	DO < 5	39%	39%
	DO < 3	7%	11%

Assawoman Bay

All fixed sites met the summer median threshold of 5 mg/L (Figure 4.3.2); however, minimum daytime values between 3-5 mg/L were observed at stations XDN7545, XDN6454, and GET0005 (Figure 4.3.3).

No continuous monitoring data were available. Threshold failures may be present if diel measurements were available, since daytime values were frequently between 5 and 6 mg/L.

Spatially-intensive data revealed a majority of Assawoman Bay meeting the DO threshold (Figure 4.3.4). A few sites along the southern approach to Grey's Creek, in dead-end canals along Fenwick Island, and on the approach to Roy's Creek in Delaware did not meet the 5 mg/L threshold.

St. Martin River

Two sites, Bishopville Prong (XDM4486) and mainstem river (XDN4312), failed the three year median of <5 mg/L, but no site had a summer median of less than 3mg/l (Figure 4.3.2). Instantaneous minimum values of < 3mg/L were observed throughout the river (Figure 4.3.3).

The continuous monitoring station on Bishopville Prong did not meet DO thresholds, 5 and 3 mg/L, 59.3% and 29.5% of the time, respectively, in 2002, a dry year (Table 4.3.2). In 2003, a wet year, DO thresholds failed 66% and 47% of the time between March 1 and November 30 (Table 4.3.2).

During August of 2001, spatially intensive sampling showed that a majority of the St. Martin River did not meet the DO threshold (Figure 4.3.4). Several sites in the upper tributaries fell below 3 mg/L.

Isle of Wight Bay

All open bay sites met >5 mg/L threshold but tributary stations in Manklin Creek (MKL0010) and Turville Creek (TUV0011 and TUV0019) failed the median of 5 mg/L (Figure 4.3.2). The Manklin Creek site had a summer median of < 3 mg/L. This station had sustained low DO due to its depth (Figure 4.3.3).

Two sites failed the instantaneous minimum of 3 mg/L in Manklin Creek (instantaneous value < 1.5 mg/L), as well as one non-tidal site on Turville Creek (TUV0034) (Figure 4.3.2).

Continuous monitoring data on Turville Creek showed that the 5 and 3 mg/L criteria were not met 39% and 7.4% of the time in 2002, respectively. In 2003, DO thresholds failed 39 and 11% of the time (Table 4.3.2).

Most of the Isle of Wight Bay proper met the DO threshold during spatially intensive sampling (Figure 4.3.5). However, areas in Manklin, Turville, and Herring Creeks were mostly below the threshold level.

Sinepuxent Bay

All sites met the summer median threshold of >5 mg/L and the instantaneous minimum threshold of 3 mg/l (Figures 4.3.2, 4.3.3, and 4.3.4 respectfully).

No continuous monitoring data were available. Some thresholds may not have been met if diel data were available since daytime values were frequently between 5 and 6 mg/L DO.

A majority of Sinepuxent Bay had DO levels above the threshold during spatially intensive sampling (Figure 4.3.5). One area that failed the threshold was located in the commercial harbor opposite the Ocean City Inlet. A few other sites failed along the western shore of this bay segment.

Newport Bay

All stations met the > 5 mg/L summer median except Marshall Creek (MSL0011) and the mouth of Newport Creek (NPC0012) (Figure 4.3.2).

Marshall creek and the mouth of Newport Creek failed the instantaneous minimum of 3 mg/L threshold (Figure 4.3.3).

Fluctuations in DO were investigated by ASIS over three time periods at a site on Trappe Creek during 2003. Dissolved oxygen concentrations during June fluctuated by as much as 5 mg/L during one day/night cycle and DO fell below 5 mg/L 12 percent of the time. During the July/August deployment, similar fluctuations during a diel period were noted and 40 percent of the values did not meet the 5 mg/l threshold. During mid-September, water temperatures moderated from summer highs and diel fluctuations of dissolved oxygen values were much smaller and all values were above threshold levels.

Varying DO levels were recorded during spatially intensive sampling (Figure 4.3.4). All sites in Trappe Creek failed the threshold. The open bay had an east-west gradient of passing to failing the DO threshold.

Chincoteague Bay

All sites met summer median of 5 mg/L threshold and instantaneous minimum >3 mg/l thresholds (Figures 4.3.2 and 4.3.3, respectfully). Mid-bay stations may fail threshold if diel data were collected since daytime values frequently between 5 and 6 mg/L.

Dissolved oxygen was measured at Taylor Landing as part of a study initiated by ASIS during the summer of 2003. During the first sampling period (June), dissolved oxygen concentrations fluctuated widely during each diel period with concentrations dropping below threshold levels three percent of the total time. The second sampling period also had widely fluctuating DO concentrations with seven percent of samples being below habitat criteria. Fluctuations in DO concentration were not as large during the fall sampling period (mid-September). No values were found below threshold levels during this time period.

Most of Chincoteague Bay met the DO threshold during spatially intensive sampling. Those sites that failed were mostly in coves or along the shoreline, especially around Figgs Landing and Green Run Bay.

Summary

Although the Coastal Bays are shallow lagoons, which typically do not stratify, oxygen values were found to be frequently low in some areas. Daytime measurements show that DO falls below 5 mg/L during the summer months throughout the St. Martin River and areas of Newport Bay, as well as in Manklin Creek, Herring Creek, Turville Creek and areas in Chincoteague Bay near Figgs Landing and Green Run Bay (macroalgae spatial data). Areas that have <5 mg/L DO during the day may provide extremely stressful habitat at night.

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).

Observed low DO values were presumably due to the respiration of large algae blooms (caused by increased nutrients), high sediment oxygen demand from organically enriched sediments in many areas (Wells and Conkwright 1999; UMCES 2004), the decay of phytoplankton, macroalgae, seagrasses, and/or marsh vegetation, and poor circulation.

Dissolved oxygen indicators can be problematic in an unstratified, shallow system especially when relying primarily on daytime measurements (which can be highly variable). One recommendation is that continuous monitors be placed in all bay segments to better track low oxygen events that can impact resources.

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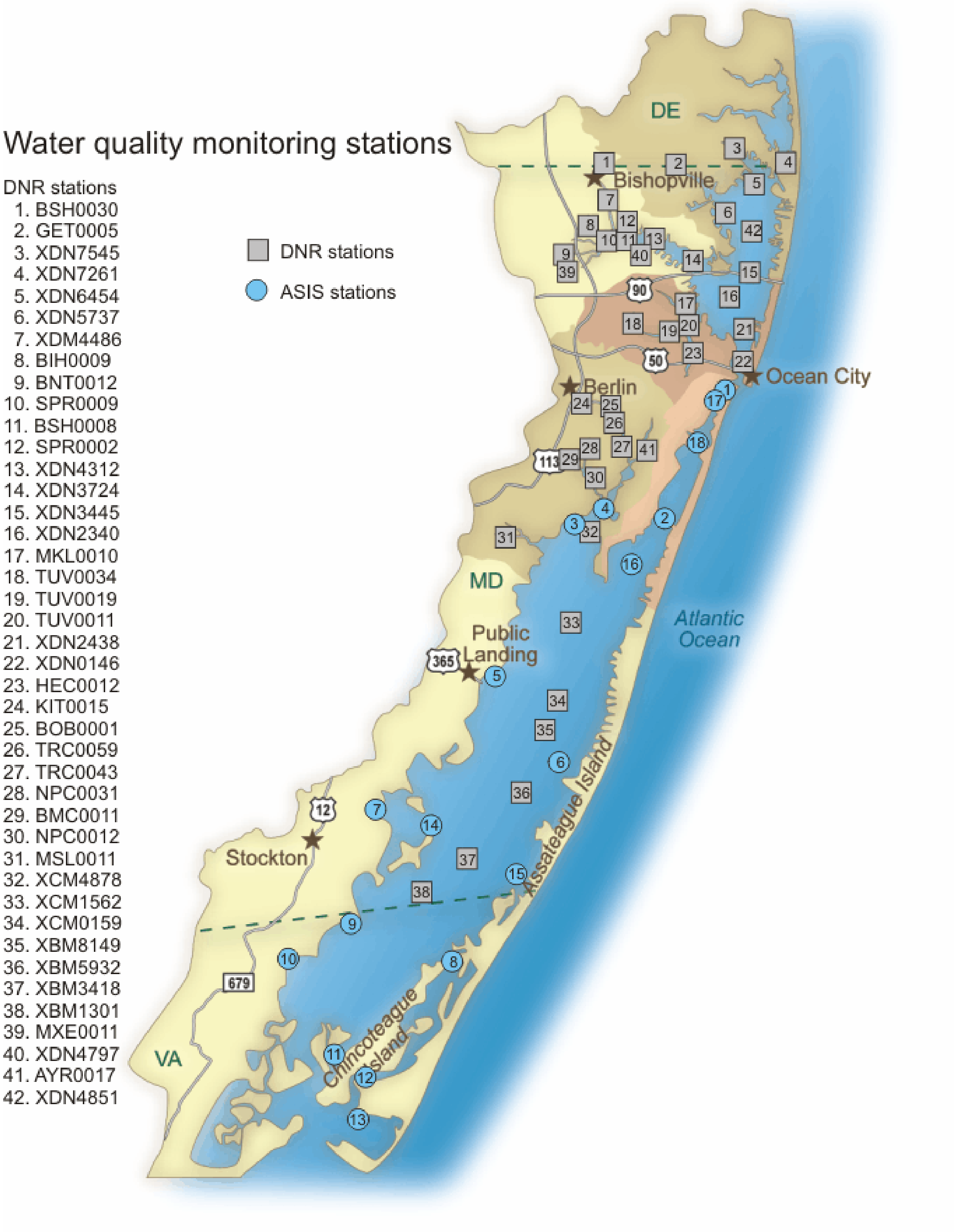

Figure 4.3.1: Map showing water quality monitoring stations for the Maryland Department of Natural Resources (DNR) and the National Park Service, Assateague Island National Seashore (ASIS). DNR stations are listed by DNR code; ASIS stations are referred to as ASIS or MCBP and the station number (for example, ASIS 1).

Figure 4.3.2: Median concentrations of Dissolved Oxygen in Coastal Bays fixed monitoring stations during the summers (June-September) of 2001 through 2003. Status categories are based on threshold values described in the text.

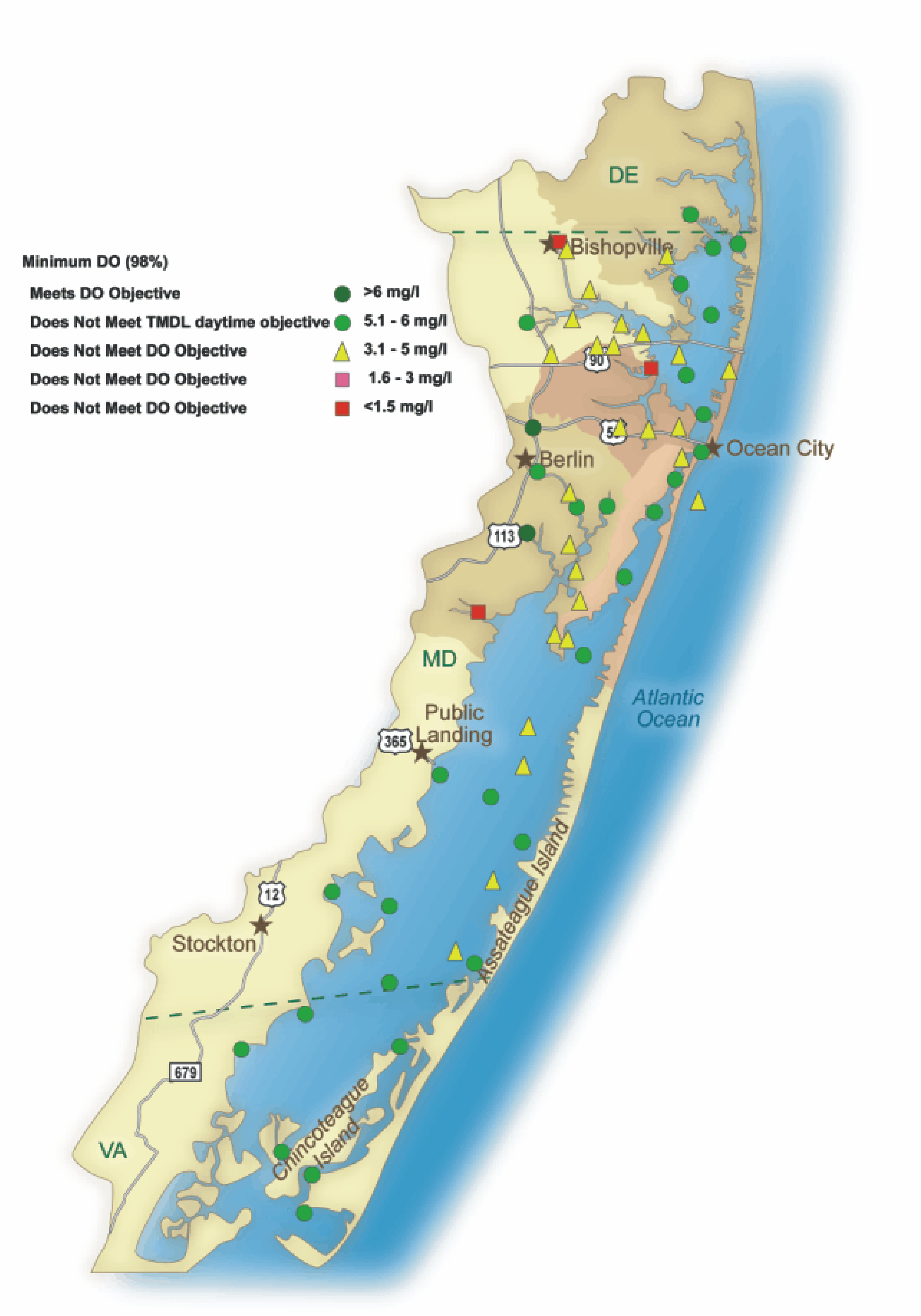

Figure 4.3.3: Minimum concentrations of Dissolved Oxygen (DO) in Coastal Bays fixed monitoring stations during the summers (June-September) of 2001 through 2003, only those minimum values falling within 98% confidence limits were included. Objectives were determined by TMDL analyses conducted for Newport Bay and St. Martin River.

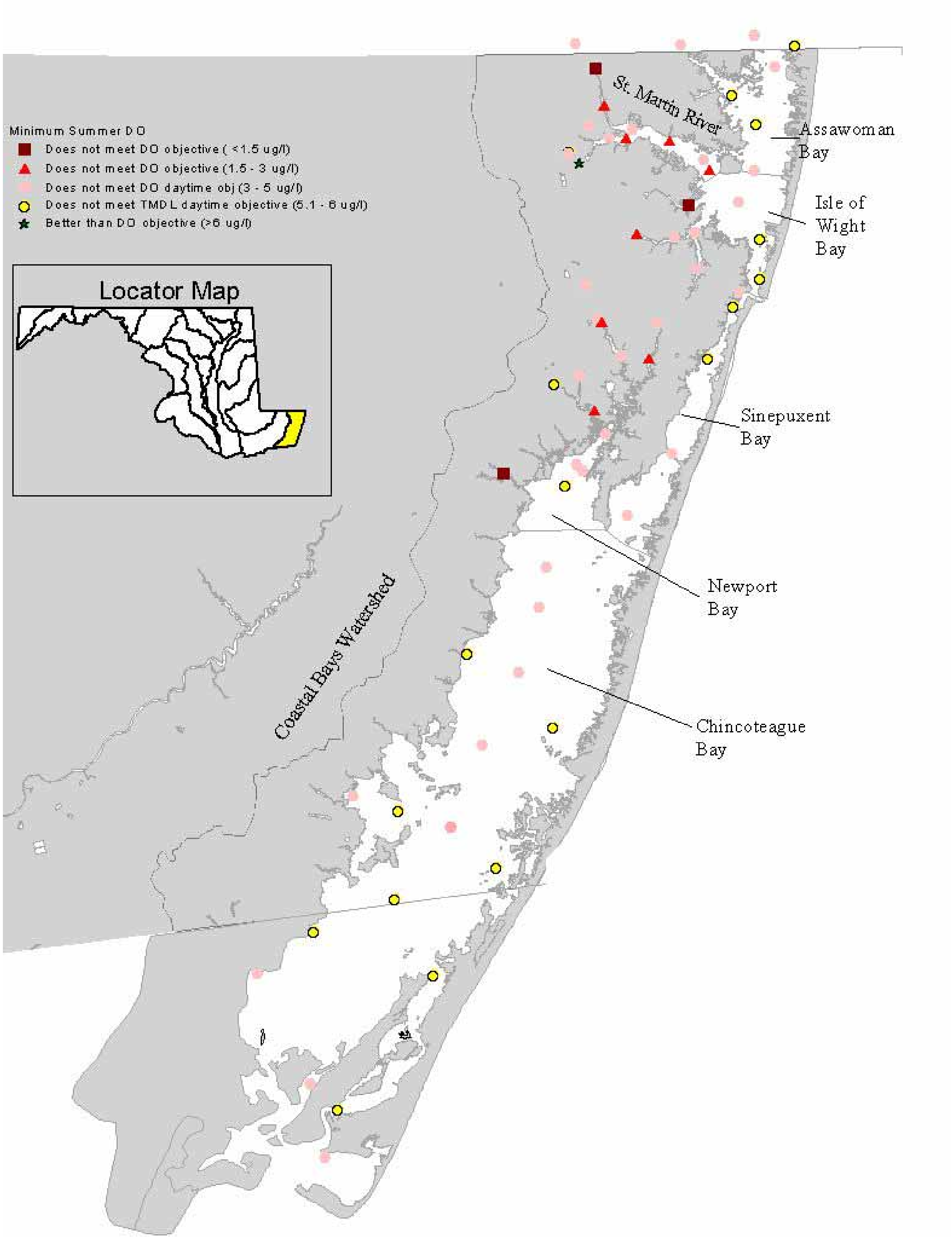

Figure 4.3.4: Observed minimum concentration of Dissolved Oxygen (DO) at Coastal Bays fixed monitoring stations during the summer months (June-September) of 2001 through 2003.

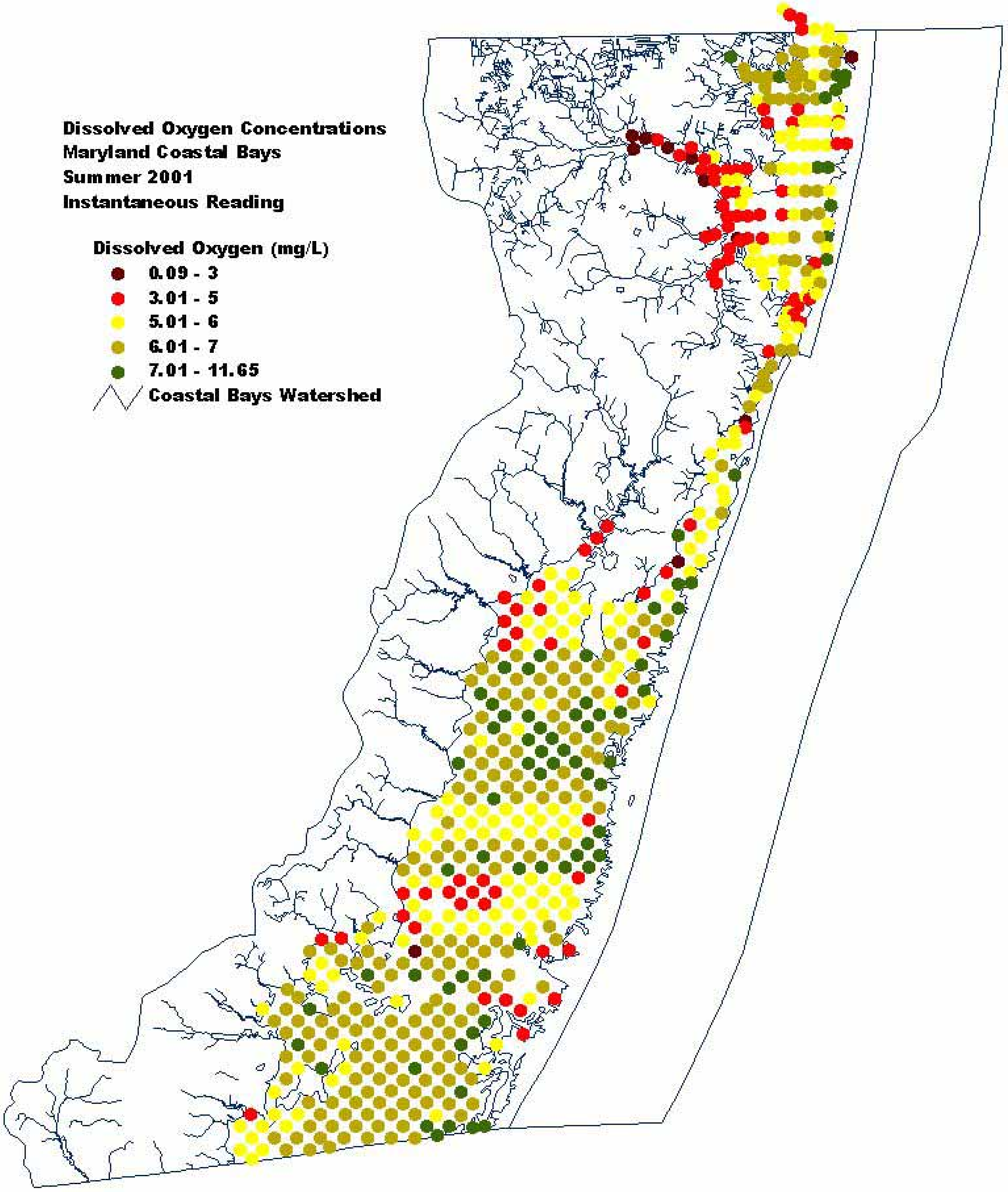

Figure 4.3.5: Instantaneous DO measurements taken during summer macroalgae sampling in August of 2001. This data provides a spatially intensive snapshot of late summer DO levels. Map created by M. McGinty (DNR).

Chapter 4.4

Development of a Water Quality Index for 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. A score of one indicates habitat suitable for fish and aquatic grass survival, while a value of zero indicates unsuitable habitat for either fish or aquatic grasses. Intermediate values indicate the system is variable and that some ecosystem functions (grass beds or fish) may be expected to be present some of the time. Currently, the tributaries generally show poor to very degraded water quality largely due to high nutrient inputs, while the open bays have good to excellent water quality.

Introduction

The Water Quality Index 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 64 sampling sites with at least 10 records for all variables between 2001 and 2003, 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: Stevenson et al. 1993; 3: Anonymous 2000, 4: Stevenson et al. 1993).

Variable	Threshold value	Reference
WQI		
Chl a	$< 15\ \mu g\ L^{-1}$	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 max for stream, not really improved water quality in these areas).

Assawoman Bay

Within Assawoman Bay, four sites were degraded and another two sites had poor water quality condition (Figure 4.4.1). This is largely due to high nutrient inputs as no sites passed TN or TP thresholds, while currently, all sites passed DO threshold (Table 4.4.2).

St. Martin River

Two sites in St. Martin River were very degraded, five degraded, and the remaining six sites had poor water quality (Figure 4.4.1). All sites failed TN and TP thresholds suggesting that high nutrient loading to these regions is reducing water quality. Broader impacts of these nutrients are becoming evident in this region, with half the sites failing chlorophyll thresholds and the two very degraded sites also failing to meet the DO threshold (Table 4.4.2). There is a slight improvement from degraded to poor water quality upstream. This was largely driven by lower chlorophyll values upstream, resulting from the lower salinity as these upstream sites had some of the highest nutrient concentrations (Table 4.4.2).

Isle of Wight Bay

Within the Isle of Wight region, a clear distinction occurred between open bay sitesand tributary sites. The three open bay sites all had good water quality; while three tributary sites had poor and two (Manklin and Turville Creeks) had degraded water quality conditions (Figure 4.4.1). No sites passed the TP threshold and while the three open bay sites passed the TN threshold, all tributary sites exceeded the TN threshold (Table 4.4.2).

Sinepuxent Bay

Overall Sinepuxent Bay had good water quality (Figure 26). 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 in these three sites (Table 4.4.2, Figure 4.4.1).

Newport Bay

Most sites in Newport Bay were degraded or very degraded, while one lower bay site had excellent condition (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 saturated in headwaters).

Chincoteague Bay

Mainstem sites in northern Chincoteague Bay (public landing and north) had poor water quality (due to nutrients), while other sites had good to excellent water quality (Figure 4.4.1). Northern Chincoteague failed TN and TP thresholds but many sites in the southern region of Chincoteague also failed to meet the TP threshold (Table 4.4.2). All sites passed chlorophyll and DO thresholds.

Table 4.4.2: Breakdown of WQI variables by region (mean$_{(se)}$)

Bay Segment	Chl	TN	TP	DO
Assawoman	0.33 $_{(0.21)}$	0.00 $_{(0.00)}$	0.00 $_{(0.00)}$	1.00 $_{(0.00)}$
St. Martin	0.46 $_{(0.14)}$	0.00 $_{(0.00)}$	0.00 $_{(0.00)}$	0.85 $_{(0.10)}$
Isle of Wight	0.89 $_{(0.11)}$	0.33 $_{(0.17)}$	0.00 $_{(0.00)}$	0.89 $_{(0.11)}$
Sinepuxent	1.00 $_{(0.00)}$	1.00 $_{(0.00)}$	0.40 $_{(0.24)}$	1.00 $_{(0.00)}$
Newport	0.43 $_{(0.14)}$	0.14 $_{(0.10)}$	0.14 $_{(0.10)}$	0.86 $_{(0.10)}$
Nth Chincoteague	1.00 $_{(0.00)}$	0.33 $_{(0.21)}$	0.17 $_{(0.17)}$	1.00 $_{(0.00)}$
Sth Chincoteague	1.00 $_{(0.00)}$	1.00 $_{(0.00)}$	0.27 $_{(0.14)}$	1.00 $_{(0.00)}$

NB: (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 south Chincoteague exhibited excellent water quality, north Chincoteague had good water quality, Isle of Wight had poor water quality, and Assawoman, St Martin and Newport all displayed 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 high phytoplankton 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 by Region

Region	n (sites)	WQI $_{(se)}$	Health
Assawoman	6	**0.33** $_{(0.05)}$	Degraded
St Martin	13	**0.33** $_{(0.05)}$	Degraded
Isle of Wight	9	**0.53** $_{(0.07)}$	Poor
Sinepuxent	5	**0.85** $_{(0.06)}$	Excellent
Newport	14	**0.39** $_{(0.08)}$	Degraded
Nth Chincoteague	6	**0.63** $_{(0.09)}$	Good
Sth Chincoteague	11	**0.82** $_{(0.04)}$	Excellent

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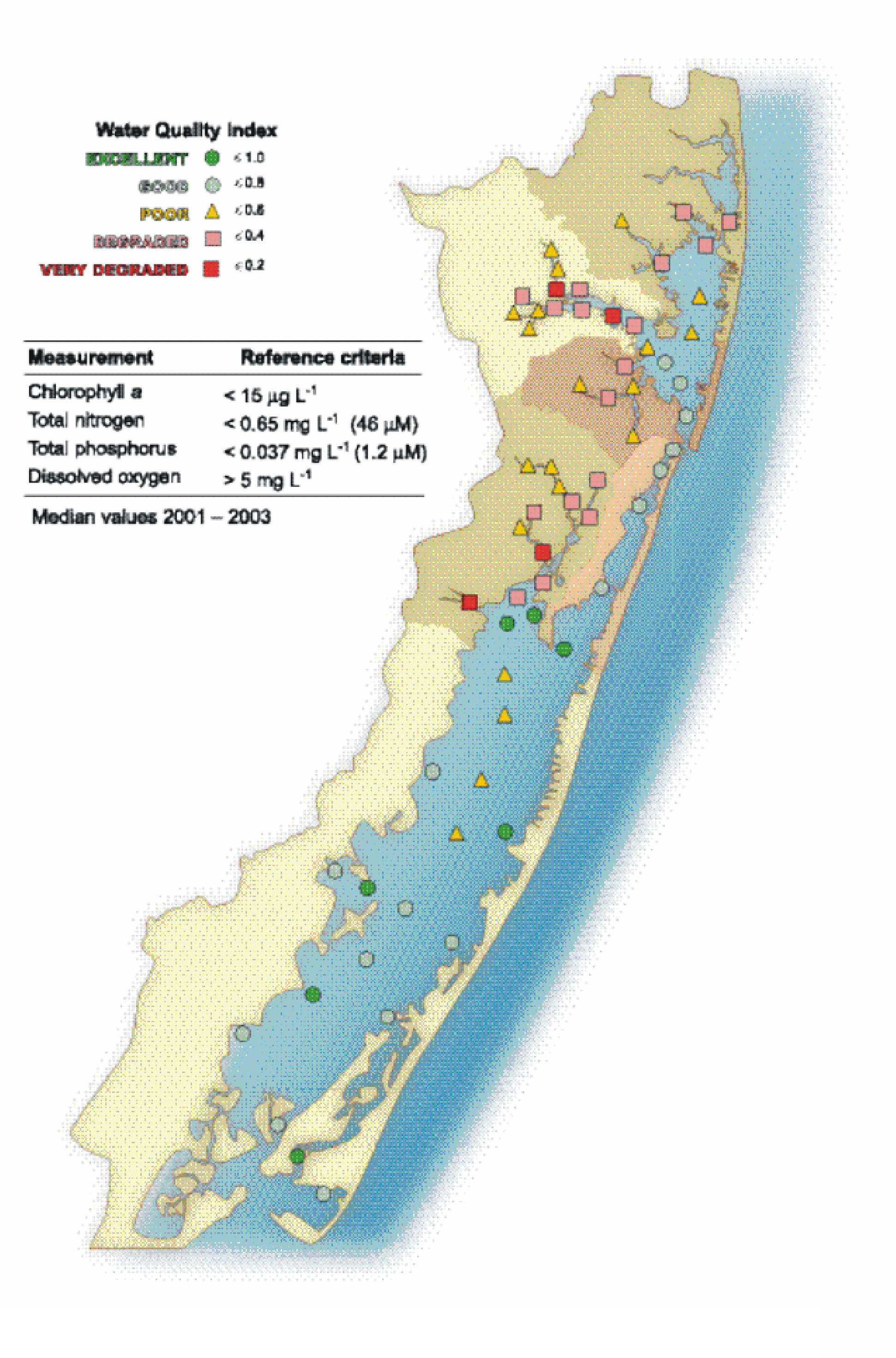

Measurement	Reference criteria
Chlorophyll *a*	$< 15\ \mu g\ L^{-1}$
Total nitrogen	$< 0.65\ mg\ L^{-1}$ (46 μM)
Total phosphorus	$< 0.037\ mg\ L^{-1}$ (1.2 μM)
Dissolved oxygen	$> 5\ mg\ L^{-1}$

Median values 2001 – 2003

Figure 4.4.1: Water Quality Index values for all fixed sampling stations based on amalgamated median indicator values.

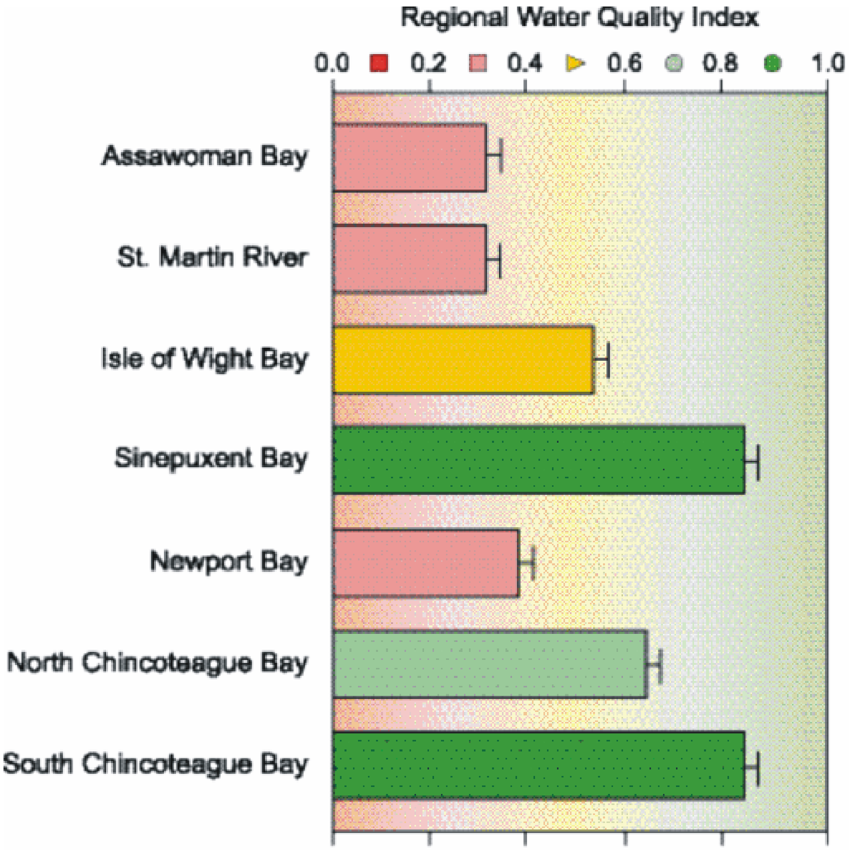

Figure 4.4.2: Overall Water Quality Index values for each of the Coastal Bays.

Chapter 4.5

Benthic chlorophyll measurements in the Maryland Coastal Bays

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Abstract

Benthic chlorophyll was measured as part of the National Coastal Assessment Program in 2002 at 124 sites (Figure 4.5.1) and 2003 at 152 sites (Figure 4.5.2). This data shows that benthic microalgae or micro-phytobenthos play a significant role in the Coastal Bays and may even be greater than water column plankton biomass in some areas. Recommend benthic algae sampling (biomass and community species composition) should be incorporated in monitoring and research efforts.

Introduction

Benthic microalgae are single-celled microscopic plants (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 (a measure of quantity) of benthic microalgae can be important in determining the total effect on the water column of the microalgal communities' growth and decay. Benthic microalgae may make up a large proportion of the total biomass of estuarine microscopic plants (McComb and Lukatelich 1986) and have been found to be up to 17% of the total production in a European estuary (de Jong and de Jonge 1995) and the most productive marine plants 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 benthic microalgae. These include; season, irradiance, concentrations of N, P and Si, 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 benthic microalgae 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 benthic microalgae 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 (1995) reported that primary production was more or less equally distributed between the surficial millimetre 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 2002 at 124 sites (Figure 4.5.1) and 2003 at 152 sites (Figure 4.5.2).

Management Objective: None currently

Benthic Chl Indicator: None currently

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 **2002** three replicate samples for benthic chlorophyll were collected at 124 sites. For benthic Chlorophyll, a small sample (approximately 5 cm^2) from the top one centimeter of sediment collected via a Van Veen grab sampler was scooped into a 50 ml centrifuge tube. The sample was kept on ice in the dark while on board, and frozen at the end of the day pending analysis. Samples were analyzed at the Chesapeake Biological Laboratory (CBL) according to the fluorometric method of Strickland & Parsons (1972).

In **2003**, three replicates were collected at 152 benthic chlorophyll samples were taken from the top one centimeter of the sediment and collected with a 60 cm^3 syringe (2.5 cm diameter), transferred to a centrifuge tube and kept on ice in the dark while on board. Subsequently frozen until later analysis.

Results

The mean bay-wide, active benthic chlorophyll was 30.48 mg/m^2 in 2002 (number of sites = 99 due to QA issues) and 37.73 mg/m^2 in 2003 (number of sites = 152).

Assawoman Bay

2002 The mean bay-wide summer time benthic chlorophyll was 22.85 mg/m^2 with a standard deviation of 12.7. The minimum value observed was 9.9 mg/m^{2}and maximum observed value was 44.86 mg/m^2.

2003: The mean bay-wide summer time benthic chlorophyll was 34.7 mg/m^{2}with a standard deviation of 25.7. The minimum value observed was 13.8 mg/m^2 and maximum observed value was 122.45 mg/m^2.

Isle of Wight Bay

2002: The mean bay-wide summer time benthic chlorophyll was 30.48 mg/m^{2}with a standard deviation of 13.3. The minimum value observed was 13.3 mg/m^{2}and maximum observed value was 52.5 mg/m^2.

2003: The mean bay-wide summer time benthic chlorophyll was 67.8 mg/m^{2}with a standard deviation of 61.2. The minimum value observed was 6.4 mg/m^2 and maximum observed value was 259 mg/m^2.

St. Martin River

2002: The mean bay-wide summer time benthic chlorophyll was 19.6 mg/m^{2}with a standard deviation of 9.5. The minimum value observed was 10.6 mg/m^{2}and maximum observed value was 48.5 mg/m^2.

2003: The mean bay-wide summer time benthic chlorophyll was 30 mg/m^{2}with a standard deviation of 22.5. The minimum value observed was 12.7 mg/m^2 and maximum observed value was 84.4 mg/m^2.

Sinepuxent Bay

2002: The mean bay-wide summer time benthic chlorophyll was 73.9 mg/m^{2}with a standard deviation of 67.5. The minimum value observed was 11.1 mg/m^2 and maximum observed value was 195.6 mg/m^2.

2003: The mean bay-wide summer time benthic chlorophyll was 51.5 mg/m^2 with a standard deviation of 46.6. The minimum value observed was 10.8 mg/m^2 and maximum observed value was 177.2 mg/m^2.

Newport Bay

2002 The mean bay-wide summer time benthic chlorophyll was 22.5 mg/m^2 with a standard deviation of 18.2. The minimum value observed was 9.1 mg/m^2 and maximum observed value was 83.7 mg/m^2.

2003 The mean bay-wide summer time benthic chlorophyll was 20.6 mg/m^2 with a standarad deviation of 11.4. The minimum value observed was 11 mg/m^2 and maximum observed value was 70 mg/m^2.

Chincoteague Bay

2002 The mean bay-wide summer time benthic chlorophyll was 38.69 $mg/m^2$with a standarad deviation of 29.5. The minimum value observed was 12.4 mg/m^2 and maximum observed value was 128.3 mg/m^2.

2003 The mean bay-wide summer time benthic chlorophyll was 28.6 mg/m^2 with a standarad deviation of 29.5. The minimum value observed was 8.5 $mg/m^2$and maximum observed value was 161.2 mg/m^2.

Discussion

This data confirms the hypothesis that benthic microalgae are a major component of the autotrophic biomass throughout the MD Coastal Bays, with concentrations ranging from 8.5 to 259 mg/m^2. However, abundance was highly variable even within a sample location.

Benthic microalgae may have greater abundance than phytoplankton in some areas of the Maryland Coastal Bays. Therefore, it is likely that they may play a significant role in nutrient cycling within sediments, as well as being an important primary producer within the system. Further research is required to establish causes of variability and reliable measures of this variability to develop an effective monitoring tool. Assessment of benthic micro-algal species and community composition is also recommended. .

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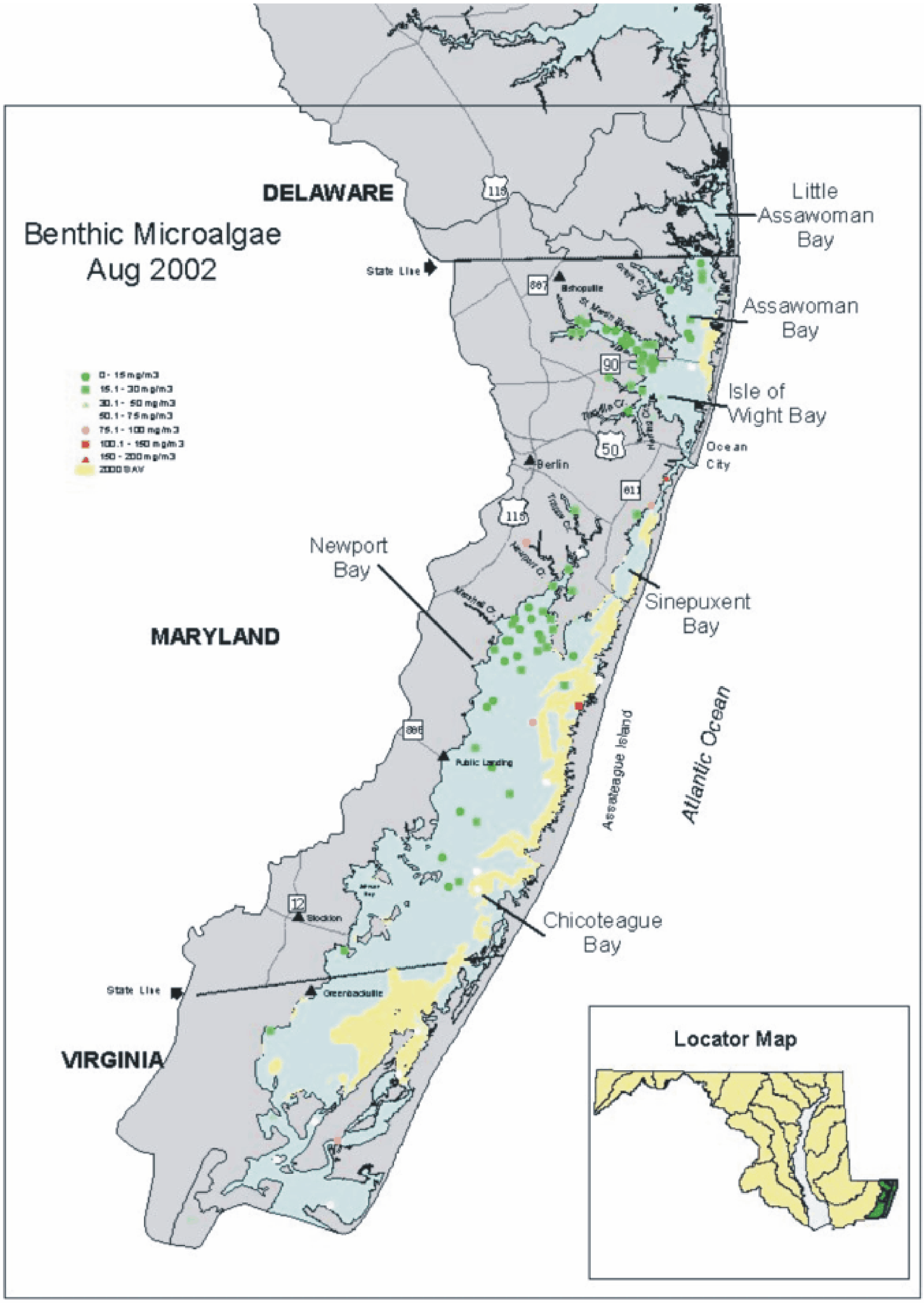

Figure 4.5.1: Benthic chlorophyll distribution during the summer of 2002.

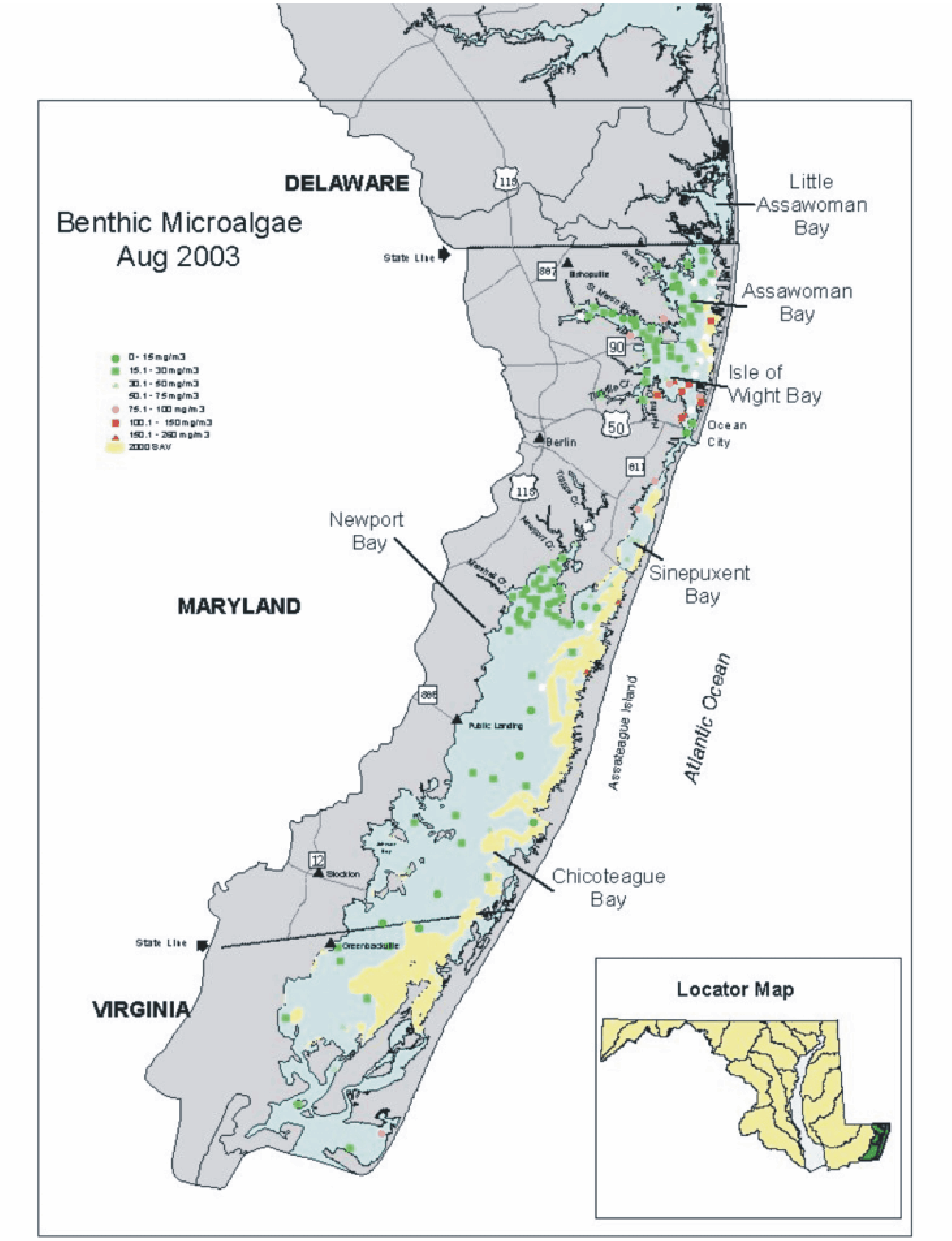

Figure 4.5.2: Benthic chlorophyll distribution during the summer of 2003.

Section 5: Sediment Quality in the Maryland Coastal Bays

General Introduction

Sediment quality is critical for seagrasses, demersal fish, and benthic communities. Sedimentation rates in the Coastal Bays are generally low, but nutrient enrichment due to human inputs is high in some areas. Chemical contamination is currently not a major threat in the Coastal Bays. However, the combined effects of 'low levels' of multiple contaminants may be impacting biological resources.

Sediment Quality Monitoring Objective: To adequately assess the types and concentrations of contaminants in sediments to inform decisions concerning inputs.

Chapter 3.1 Total organic carbon in Maryland Coastal Bays sediments: status of a regulator of chemical and biological processes

Chapter 3.2 A synthesis of sediment chemical contaminant studies in the Maryland Coastal Bays

Chapter 3.3 Ambient toxicity of sediments from the Maryland Coastal Bays

Chapter 5.1

Total organic carbon in Maryland Coastal Bays sediments: Status of a regulator of chemical and biological processes

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Abstract

Total organic carbon in sediments regulates the behavior of other chemical species such as metals. The indicator for total organic carbon was calculated as the percentage above that indicated by natural clay content in the sediment (excess organic carbon). Excess organic carbon values ranged from –0.73% to 5.12% in Coastal Bays sediments. The St. Martin River, Herring Creek, and Newport Creek were found to have high levels of excess organic carbon, a factor that may be affecting benthic communities. The open water portions of the Coastal Bays did not contain high levels of excess organic carbon.

Introduction

Total organic carbon has a major influence on both the chemical and biological processes that take place in sediments. The amount of organic carbon has a direct role in determining the redox potential in sediment, thus regulating the behavior of other chemical species such as metals.

Sources of organic carbon include organic matter from overland runoff and shoreline erosion (mostly marshes), and primary productivity within the bays, all of which eventually settle to the bay bottom and are incorporated into the sediment. Since organic matter is a primary source of food for benthic organisms, it is important in maintaining a viable ecosystem. However, too much organic matter can lead to the depletion of oxygen in the sediment and overlying water, which can have a deleterious effect on the benthic and fish communities.

Total organic carbon (TOC) content in sediments has been used as an indicator of pollution and eutrophication rate (Folger 1972; EPA 2002). Excess carbon may be attributed to either excessive plant debris (such peat from eroding marshes) or anthropogenic loading. High organic carbon in the northern bays is considered a sign of frequent algae blooms in the overlying water column, the blooms being a result of increased nutrient (nitrogen and phosphorus) loadings into the system. TOC content is proportional to organic matter, which has an affinity for trace metals and organic contaminants.

Data sets

CZM/MGS Sediment mapping report (Wells and Conkwright 1999)- providing basis for predicting TOC in sediments

EPA National Coastal Assessment Program (NCA): sediments collected in 2000 for MCBP

Management Objective: Reduce sediment inputs (MCBP CCMP 1999).

Indicator: percent Excess organic carbon (Ex-OC) $\leq$ 1%

EPA (2002) recommended the following assessment categories for TOC in sediments:
Low impact: $\leq$ 1%
Intermediate impact: 1 to 3%
High impact: >3%

The threshold values were based on EMAP data that indicated TOC values between 1% and 3% were associated with impaired benthic communities. However, these thresholds are still under evaluation.

Analyses

TOTAL ORGANIC CARBON IN MARYLAND COASTAL BAY SEDIMENTS

Wells and Conkwright (1999) found that clay content in Coastal Bays sediments is a very good indicator of minimum values for carbon content (Figure 5.1.1). For example, sediment consisting of 25% clay-size particles would be expected to contain at least 1.25% total carbon. They also determined that organic carbon accounts for 90% of total carbon in Coastal Bays sediments. Therefore, clay content (% clay-sized fraction) can be used to predict organic carbon content (Equation 1).

$$C_{organic} = 0.0448 * \%Clay - 0.079 \qquad \textbf{(Equation 1)}$$

Wells and Conkwright (1999) used this relationship to assess excessive carbon above "background" in the sediments of the Coastal Bays. The excess carbon is interpreted as increased organic input due to anthropogenic activities. They found that the sediments collected in the upstream areas of Roy Creek, Greys Creek, Trappe Creek, and St. Martin River were excessively enriched in total carbon

Excess organic carbon is calculated for the NCA/MCBP 2000 data using Equation 1. Because clay content was not measured, moisture (%water) and siltclay (mud%) were used to calculate clay content (Equation 2). This equation was derived from regression analyses of the textural parameters of 963 sediment samples collected by Wells and Conkwright (1999).

$$\%Clay = 0.309\ (\%Mud) + 0.0557\ (\%Water) \quad (R^2 = 0.949)$$ **(Equation 2)**

Excess organic carbon values ranged from –0.73% to 5.12%. Values between –1 and 1% are within the error of the prediction model, thus these were considered to be within normal levels. Figure 5.1.2 shows the distribution of excess organic carbon (Ex-OC) in the Coastal Bays based on sediment data collected in 2000. Excess organic carbon assessment categories are similar to those suggested by EPA (2002):

Low : ≤ 1%
Intermediate 1 to 3%
High: >3%

Summary

St. Martin River, Herring Creek and Newport Creek have excessively organic rich sediments, which may have an impact on benthic communities. Sediments in the open water areas of the bays are not enriched in organic carbon. Except for one station in Isle of Wight Bay, Ex-OC values fall with those reported by Wells and Conkwright (1999).

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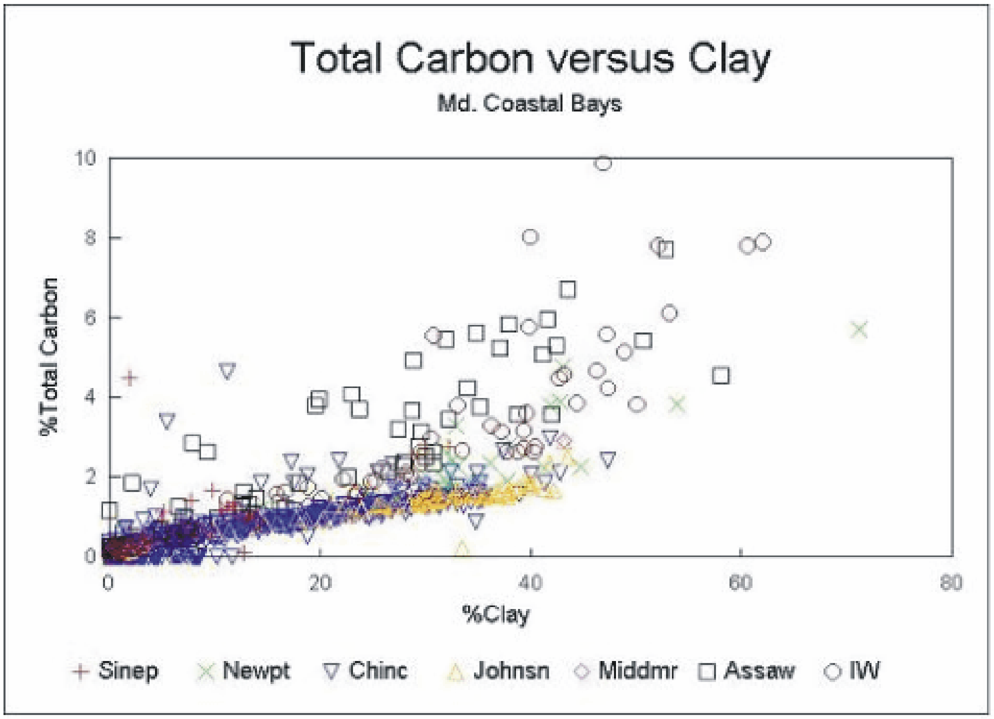

Figure 5.1.1: Plot of total carbon versus clay content for 963 surficial sediment samples collected in the coastal bays between 1991 and 1995 (Wells and Conkwright, 1999). Sediment samples are grouped by sub-basin. Sinep=Sinepuxent Bay; Newpt=Newport Bay; Chinc=Chincoteague Bay; Johnsn=Johnson Bay (Chincoteague); Middmr=Middlemoor Ditch (Chincoteague); Assaw=Assawoman Bay; IW=Isle of Wight Bay.

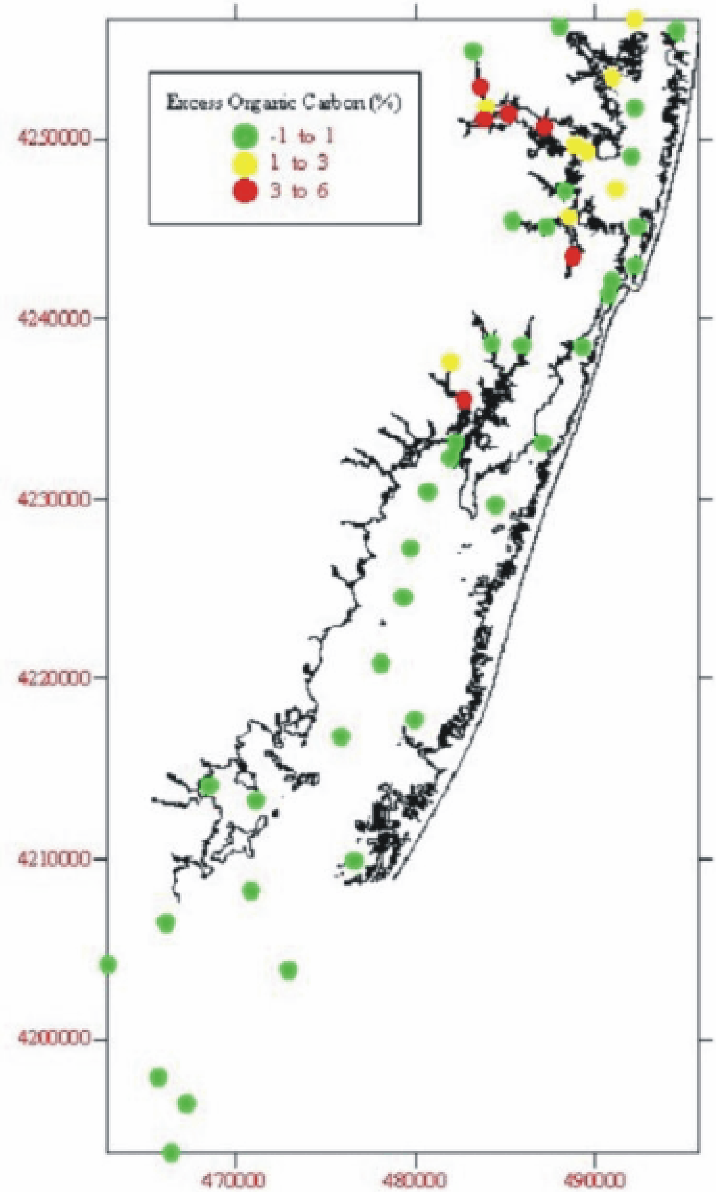

Figure 5.1.2: Map showing levels of excess organic carbon in sediments collected in 2000.

Chapter 5.2

A synthesis of sediment chemical contaminant studies in the Maryland Coastal Bays

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Abstract

Sediment contaminants, especially metals and organics, are serious threats to estuarine ecosystems worldwide. This chapter summarizes sediment contaminant studies that have been conducted in the Coastal Bays, most within the last decade. EPA 1993 data indicated that overall sediment contaminants were decreasing throughout the Coastal Bays. However, this study was biased toward upper tributaries and dead-end canals, where contaminants were expected to be high. The National Coastal Assessment 2000 study was the most comprehensive to date, indicating that sediment contamination levels were low throughout the southern and open water northern Bays. Higher contaminant levels were restricted to localized areas in tributaries in the northern bays and in Newport Creek.

Introduction

Sediment contaminants**,** metals and organics, in sediments have been identified as a serious environmental problem in estuaries around the world. Contaminants are introduced into the Coastal Bays from run-off, direct discharge, and atmospheric deposition. While metals are found naturally in the near marine and marine environment, enrichment over background levels of certain trace metals can be attributed to human activities (Table 5.2.1). Organic contaminants, which include, but are not limited to, pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons, (PAHs) come from anthropogenic sources.

Most contaminants tend to bind onto fine-grained particles that eventually settle to the bottom of the bays. In low energy areas (e.g. dead-end canals) contaminants bind to sediments close to where they were introduced into the environment. Once in the sediments, the contaminants can have an adverse effect on the benthic organisms living in the sediments, resulting in lower biodiversity and/or abundance if contaminant concentrations are high enough. Even in trace or very low concentrations, benthic organisms can ingest the contaminants, accumulate the toxins in their tissue, and result in concentrations higher than those in the surrounding sediments. Additionally, contaminants may become more concentrated as they are work their way up the food chain (bioaccumulation).

Several approaches have been developed to assess the levels of sediment contaminants in terms of their potential toxicity to the benthic and fish community. Most approaches calculated threshold values of individual contaminants based on observed toxic effects on sensitive benthic animals. Long et al. (1995) determined two criterion limits, the Effects Range-Low (ERL) and the Effects Range Median (ERM) for 41 contaminants (including 9 metals, 13 PAHs, total PCBs and 10 other organic contaminants) based on correlative analyses of existing laboratory toxicity data, field studies and model data. They defined ERL values and ERM values as those concentrations above which adverse biological effects were seen in 10% and 50%, respectively, of the data reviewed. Another criterion limit is the Apparent Effects Threshold (AET) values derived from a correlation of the weight of evidence from multiple matched chemical and biological effects data sets (laboratory toxicity testing on field sediment samples). The AET value for a particular contaminant is defined as the sediment concentration above which an adverse biological effect is always statistically observed (U.S. EPA, 1992). AET values are available for 19 elements and 50 organic compounds (Buchman, 1999). AET threshold values for most of the contaminants fall between ERL and ERM values (Table 5.2.2).

Table 5.2.1: Sources of major toxic chemicals in the Coastal Bays.

Toxic Chemical or Chemicals	***Type of Toxic Chemical***	***Primary Uses or Sources***	***Comments***
DDT, DDE, DDD	Chlorinated Hydrocarbon	Insecticides and their breakdown products	Banned in the USA.
Chlordane	Chlorinated Hydrocarbon	Mix of several chlorinated insecticides	Use on crops banned in USA in the 1970s. Use for termite control stopped in 1980s.
PAH	Polycyclic Hromatic Hydrocarbon	Oil spills, by-products of combustion, creosotes, tars, natural sources	Naturally occurring substances but abundance has been greatly increased by human activity.
PCBs	Polychlorinated Biphenyls	Used in electrical transformers and capacitors	Banned for use in new equipment in the 1970s. Still found in some older equipment.
Tributyl tin, dibutyl tin, monobutyl tin	Organo-metallic Compounds	Antifouling paints and their breakdown products	Banned for use on vessels under 70 feet long.
Copper	Metal	Antifouling paints, wood preservatives, auto part wear, insecticides, plumbing	
Arsenic	Metal	Wood preservatives, pesticides	
Nickel	Metal	Paints and finishes	
Zinc	Metal	Galvanized metals, sacrificial anodes to prevent corrosion of metals in seawater, pigments in paints	
Lead	Metal	Paints, leaded fuels, batteries, plumbing	Use in auto fuels banned, sharply reducing releases.
Chromium	Metal	Chrome plating of metals	
Cadmium	Metal	Batteries, paints, pesticides	

The presence of multiple toxins in the environment is unclear but is thought to work simultaneously and compound the stress of any individual toxin on aquatic organisms. Long and others (1998) used mean ERM quotients as a technique to rank potential toxicity of sediments containing multiple contaminants. They found that as the mean ERM quotients increased, the incidence of toxic responses increased. The mean ERM quotient is calculated as the average of individual quotients obtained by dividing the concentration of each chemical contaminant by their respective ERM value. For the MCBP State of the Bay Report, mean AET quotient is used as the indicator to quantify potential sediment toxicity. Quotients based on AET threshold values are used primarily because ERM threshold values are not available for pesticides other than DDT.

Data Sets

USACE 1997 – West O.C. Fishing Harbor sediments tested for chemical and particle size.

CZM/MGS Sediment mapping report (Wells and others, 1999): metals, sediments collected between 1991 and 1996 (total of >900 sites);

EPA EMAP – Joint Assessment (Chaillou and others, 1996: metal and organic contaminants, sediments collected in 1993) – 13 sites analyzed for contaminants in MD.

EPA MAIA 1997-98 data – 25 sites analyzed for sediment contaminants, however, no sites were in northern two bays (north of Ocean City Inlet).

EPA National Coastal Assessment Program (NCA): sediments collected in 2000 and 2001 at 54 stations throughout the Coastal Bays.

Management Objective: none.

Draft Indicators
ERLs, ERMs, AETs (NOAA SQRT Tables), mean AET quotient

CRITERIA:
Trace metals: establish baseline data (MGS) and compare with more recent data sets noting any significant differences; ERM quotient (both metals and organics)
Organic contaminants: number of sediment contaminants exceeding ERL, ERM threshold values; change in AET quotient (based on both metals and organics)

Indicator 1: ER-L and ER-M values
Indicator 2: Apparent Effects Threshold Quotient

Results
Historical Data
Most of the information on sediment contaminants in Maryland's Coastal Bays has come from studies conducted within the last ten years. Between 1991 and 1995, the Maryland Geological Survey conducted an intensive sediment sampling in the Maryland Coastal Bays, collecting over

900 surficial sediment samples (Wells and Conkwright, 1999). They analyzed the sediments for total carbon, nitrogen and phosphorus and seven metals (cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc). They found that generally the bottom sediments in the Maryland's Coastal Bays did not contain excessively high concentrations of metals. While none of the samples contained metal concentrations exceeding the ERM values, sediments collected in St. Martin River, near marinas and along developed shorelines showed elevated level above background (historical) levels of copper and zinc.

In 1993, the Coastal Bays Joint Assessment (CBJA) collected water and sediment samples in an effort to characterized the Maryland and Delaware Coastal Bays (Chaillou et al., 1996). Because of budget constraints, CBJA analyzed sediment from 36 of the 200 sites sampled, and of those 36, only 16 were in Maryland's Coastal Bays (Figure 5.2.1). The sediments were analyzed for 15 elements, and 66 organic toxins. Chaillou and others (1996) noted that the number of contaminants exceeding the ERL limits increased from south to north. In Maryland, all but three samples contained one or more contaminants exceeding ERL values. Total chlordane concentrations exceeded ERL values in all but one sample. Arsenic and total DDT concentrations exceeded ERL values in half of the samples. The samples containing the most contaminants exceeding ERLs were collected in a dead-end canal in Assawoman Bay and in Trappe Creek. The sediment collected in the dead-end canal in Assawoman Bay was the only sample to contain a contaminant (Benz(a)anthracene) exceeding the ERM level. The authors concluded that the chlorinated hydrocarbons, the primary sediment contaminants detected, are remnants from historic inputs.

In 1997, EPA collected water and sediment samples in four estuarine systems in the mid-Atltantic region (USEPA, 2002). Data for Maryland Coastal Bays included 16 samples taken in lower bays (Sinepuxent, Newport, and Chincoteague Bays) and did not include the northern bays (Assawoman and Isle of Wight Bays). EPA ranked Chincoteague and Sinepuxent Bays as "good", meaning less than 20% of bay area have impaired values for organic contaminants in the sediments. Sinepuxent Bay was ranked as "good" with regard to metal contaminants in the sediments while 20% to 40% of Chincoteague Bay showed some impairment from metal contamination (USEPA 2002).

National Coastal Assessment

In 2000, as part of the National Coastal Assessment (NCA), EPA collected surficial sediments at 54 locations matching the water quality stations monitored for the Maryland Coastal Bays Program (Figure 5.2.2). The sediments were analyzed for water, mud (silt-clay), and total organic carbon content, 15 metals, 22 PAHs, 20 PCBs, and 20 pesticides. Table 5.2.2 lists the individual chemicals and the frequency at which they were detected (i.e., number of non-zero values reported). Many of the concentrations reported were less than the minimum detection limits (MDL). It is assumed that the laboratory responsible for the analyses reported a concentration value if the signal for the contaminant could be quantified. In this discussion, reported concentration value less than the given MDL are treated as real values.

Metal And Organic Contaminants

Although two metals, antimony (Sb) and silver (Ag), were detected in most of the samples, none of the reported concentrations were above the MDL. Likewise, none of the concentrations reported for pesticides Aldrin, Heptachlor, Lindane, Mirex, and O,P'DDD, and PCB congeners 126, 170, 18, 195, 206, and 77 were above the MDL. None of the sediment samples contained detectable levels of the pesticides Endrin or Toxaphene.

Correlation analyses were performed on the textural and chemical data from sediment analyses to determine what, if any, associations the contaminant may have with each other and with sediment texture (Table 5.2.3). All reported non-zero concentration values were included in the analyses. Except for mercury (Hg) and cadmium (Cd), correlations between almost all of the metals are significant at the 95% level (p-values < 0.05). Most of these correlations are very strong ($r > 0.7$). In addition, all metals show a strong association with water and silt-clay contents. Metals typically are associated with clay minerals as they are components of the mineral lattice structure or absorbed onto clay surfaces (Cantillo, 1982). Clay minerals comprise a significantly large portion of the fine (clay-size) sediment fractions.

Correlation analyses included organic contaminants groups (i.e., total PAH, DDT, PCB) instead of individual contaminants. Total DDT, total PCB and total DDT were obtained by summing the concentrations (including values below the MSD) of the individual contaminants in the respective chemical group. Total DDT and total PCB are significantly correlated with water and silt-clay content and most metals. Total PAH, on the other hand, shows little or no significant correlation with any of the other variables, suggesting that the PAH levels are not associated with a particular sediment type and/or levels are near the detection limit.

Thirty-three of the 54 samples contained at least one contaminant exceeding ERL threshold values (Table 5.2.4). Samples collected in West Ocean City harbor (MD-CB-01) and Newport Creek (MD-CB-33) contained 12 contaminants exceeding ERL values (including As, Cu, Ni, Zn, Acenaphthylene, Anthracene , Benzo(A)Anthracene, Chrysene, Fluoranthene, Fluorene, total PAHs, total DDTs). Samples collected in the St. Martin River, Bishopville Prong, Shingle Landing contained five contaminants exceeding ERL values. Sediments collected in Sinepuxent Bay and Chincoteague Bay generally had no more than two contaminants exceeding ERL values. Metals account for the majority of contaminants exceeding ERL (and AET) limits. Nickel (Ni) and arsenic (As) were the contaminants most often exceeding their ERL values, followed by zinc (Zn) and copper (Cu). The ERL values for Cu, Ni, and Zn, and AET value for Mn are at levels designated as 'background levels' found in the Maryland Coastal Bays (Wells and Conkwright 1999). The organic contaminant most often exceeding ERL value is total DDT.

None of the sediments contained contaminants exceeding their respective ERM threshold limits.

More than half the sediment samples contained at least one contaminant exceeding the AET limit. However, the maximum number of contaminants exceeding the AET limit was 3 (Site MD-CB-29 collected in St. Martin River). Like ERLs, metals account for the majority of contaminants exceeding AET limits. Most other samples contained one or two metal contaminants that exceeded AET, with manganese (Mn) being most frequent followed by chromium (Cr). The AETs reported for these metals are based on polychaete (*Neanthes*) bioassays and both values are lower than the respective ERL threshold limits (Buchman, 1999). However, the AET values for these metals are equal to background levels within the study, which demonstrates a limitation of using the sediment quality guideline (SQG) values.

Mean quotients based on AET limits (AET-Q) were calculated for each sediment sample collected in 2000 (Table 5.2.4). Although AET values are available for total chlordane, a persistent pesticide, the 2000 data did not report total chlordane values. Therefore, mean AET-Q does not account for chlordane. AET-Q is used to indicate "degree" of potential sediment toxicity based on multiple contaminant concentrations. AET-Q values range from 0.01 to 0.34 and directly related to the total organic carbon in the sediment (Figure 5.2.3). Higher values for AET-Q are associated with organic rich sediments collected in the tributaries to the northern bays (Figure 5.2.2).

Summary

Comparison with Previous Studies

The NCA 2000 data set represents the most comprehensive surficial sediment contaminant assessment yet. Cursory comparison with earlier data set such as EMAP93 data (Chaillou and others, 1996) suggests that the overall sediment contaminants have decreased over the past 11 years. However, caution should be exercised when making this comparison. The 1993 data set was limited in coverage and biased toward the more contaminated areas such as dead-end canals and upper tributaries. In addition, EPA1993 data reported total chlordane concentrations, which exceeded ERL limits in all but one sample. The NCA 2000 data did not report total chlordane. In addition, the 1993 data set contained some inconsistencies that cannot easily be explained. For example, the sandy sediment collected in mid-Chincoteague Bay (Site 714) contained the highest concentration of heptachlor, approximately 10 times that reported for other samples. Figure 5.2.1 shows the distribution of AET-Q based on EPA1993 data. AET-Qs were calculated in the same manner as those for the NCA 2000 data and do not include total chlordane.

Conclusion

Based on the NCA 2000 contaminant data, bottom sediments in Maryland southern Coastal Bays (Sinepuxent, Newport, and Chincoteague Bays) and open water area in Assawoman and Isle of Wight Bays do not contain high levels of contaminants. Generally, concentrations for most metal are within background levels. Most organic contaminants are at trace levels or below detection limits.

Higher contaminant levels were restricted to localized areas in tributaries in the northern bays and in Newport Creek. These areas were also high in total organic carbon.

Comparison with historical data suggests that sediment contaminants, particularly organic contaminants, may be decreasing. However, the historical data are not comparable in coverage. The 1993 data set (Chaillou et al, 1996) was biased toward the more contaminated areas such as dead-end canals, and the 1997 data set (USEPA 2002) did not include the northern Coastal Bays.

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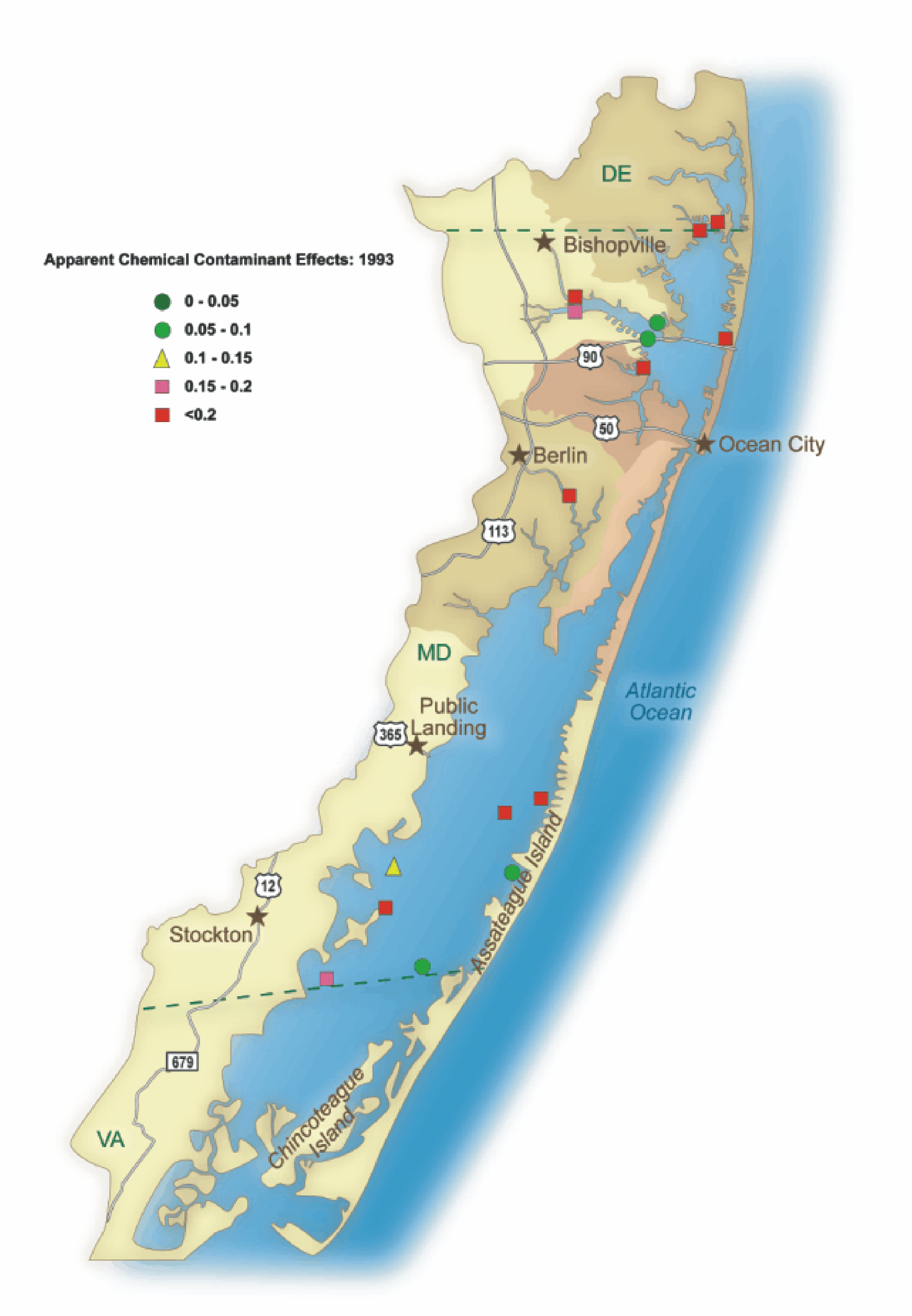

Figure 5.2.1: Map of sediment toxicity based on mean Apparent Effects Threshold (AET) values for samples collected by the Coastal Bays Joint Assessment in1993.

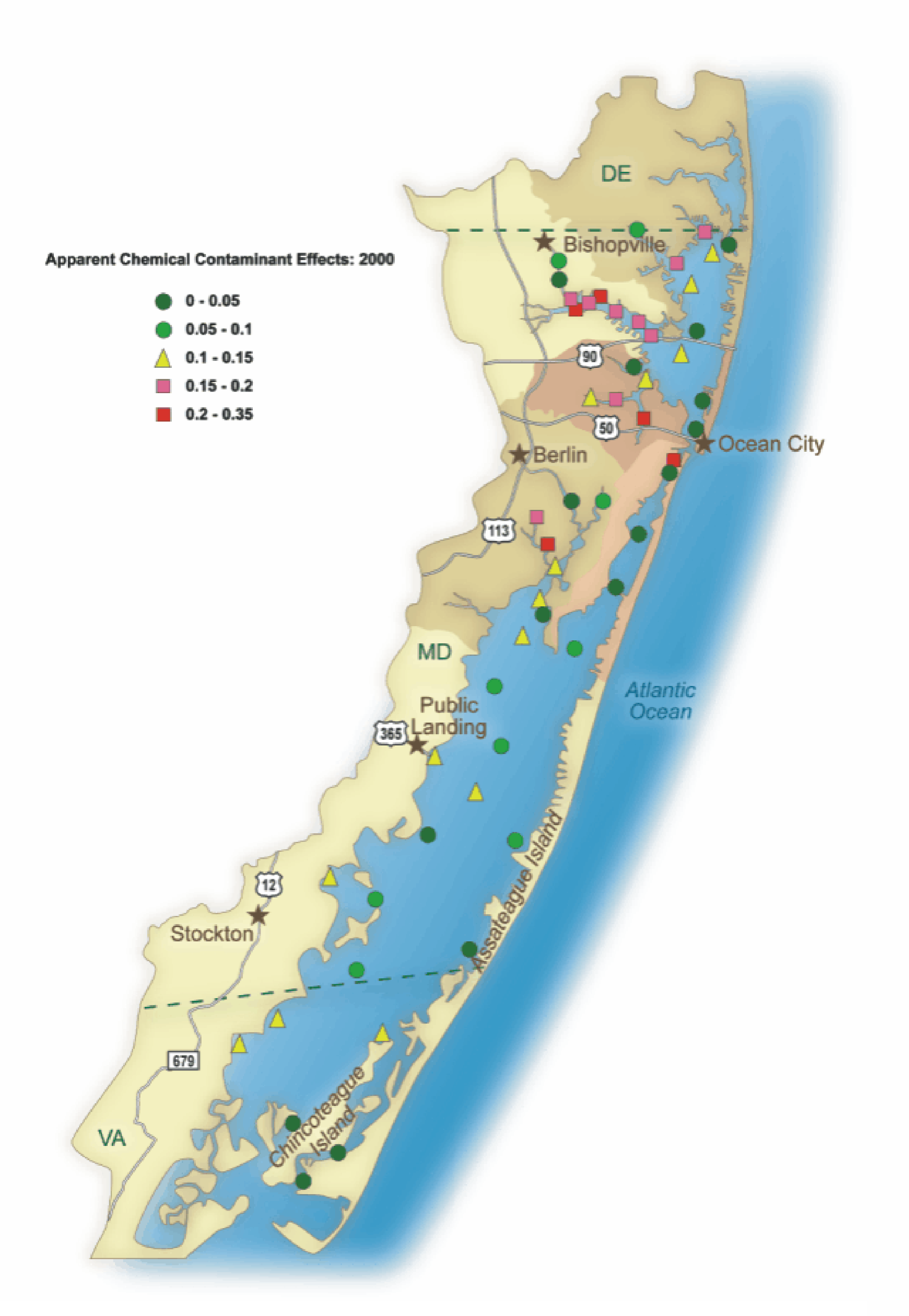

Figure 5.2.2: Map of sediment toxicity based on mean Apparent Effects Threshold (AET) values for samples collected by the Environmental Protection Agency in 2000.

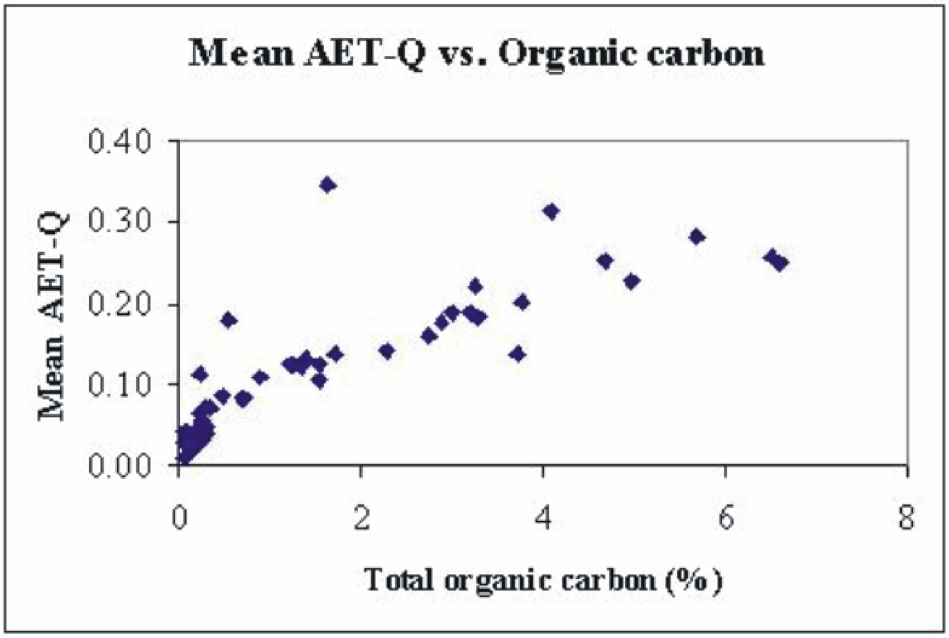

Figure 5.2.3: Plot showing the relationship between total organic carbon and mean AET-Q. The single outlier data point (AET-Q=0.34) corresponds to sediment collected in West Ocean City Harbor (see map- Figure 5.2.1; point nearest Ocean City).

Table 5.2.2: Listing of the chemical contaminants analyzed in the 54 sediment samples collected in 2000 for MCBP. The minimum detection limit for each chemical is listed along with the number of samples for which values were reported (indicating detection) and exceeded MDL. Also listed are the sediment quality guideline (SQG) values for each chemical, if available, and how many times the reported values exceeded those guidelines. Total PAHs, PCBs and DDTs were calculated as the sum of the concentration reported for the individual chemicals for each group.

Chemical Name	**Abbreviation**	**Minimum Detection Limit (MDL)**	**Frequency of concentration**		**Sediment Quality Guideline Values**			**Frequency of reported concentrations exceeded SQG values**		
			Reported (detected)	**Exceeded MDL**	**ERL**	**ERM**	**AET**	**> ERL**	**> ERM**	**> AET**
METALS										
ALUMINUM	AL	0.1	54	54						
ANTIMONY	SB	0.5	44	0	2	25	9.3	0	0	0
ARSENIC	AS	5	48	27	8.5	70	35	17	0	0
CADMIUM	CD	0.5	50	7	1.2	9.6	3	1	0	0
CHROMIUM	CR	5	54	49	81	370	62	0	0	9
COPPER	CU	5	54	38	34	270	390	7	0	0
IRON	FE	2	54	54						
LEAD	PB	0.5	54	54	46.7	218	400	0	0	0
MANGANESE	MN	5	54	54			260			28
MERCURY	HG	0.02	40	33	0.15	0.71	0.41	0	0	0
NICKEL	NI	5	54	38	20.9	51.6	110	26	0	0
SELENIUM	SE	0.1	42	34			1			1
SILVER	AG	0.5	52	0	1	3.7	3.1	0	0	0
TIN	SN	0.5	54	45			3.4			2
ZINC	ZN	5	54	54	150	410	410	9	0	0
Polynuclear Aromatic Hydrocarbons (PAH)										
(I)1,2,3-C,D-PYRENE	INDENO	1.4	51	35			600			0
1-METHYLNAPHTHALENE	MENAP1	3.1	54	11						
1-METHYLPHENANTHRENE	MEPHEN1	3.1	50	21						

Chemical Name	Abbreviation	Minimum Detection Limit (MDL)	Frequency of concentration		Sediment Quality Guideline Values			Frequency of reported concentrations exceeded SQG values		
			Reported (detected)	Exceeded MDL	ERL	ERM	AET	> ERL	> ERM	> AET
2,3,5-TRIMETHYLNAPHTHALENE	TRIMETH	3.1	34	3						
2,6-DIMETHYLNAPHTHALENE	DIMETH	3.1	46	8						
2-METHYLNAPHTHALENE	MENAP2	3.1	54	18	70	670	64	0	0	0
ACENAPHTHENE	ACENTHE	1	51	21	16	500	130	1	0	0
ACENAPHTHYLENE	ACENTHY	1	51	25	44	640	71	1	0	0
ANTHRACENE	ANTHRA	0.77	50	37	85.3	1100	280	2	0	1
BENZO(A)ANTHRACENE	BENANTH	1.2	39	37	261	1600	960	2	0	0
BENZO(A)PYRENE	BENAPY	1.8	50	33	430	1600	1100	1	0	0
BENZO(B)FLUORANTHENE	BENZOBFL	2.6	53	36			1800			0
BENZO(G,H,I)PERYLENE	BENZOP	1.4	53	36			670			0
BENZO(K)FLUORANTHENE	BENZOKFL	1.4	53	36			1800			0
BIPHENYL	BIPHENYL	0.8	50	25						
CHRYSENE	CHRYSENE	0.98	49	40	384	2800	950	2	0	0
DIBENZO(A,H)ANTHRACENE	DIBENZ	1.2	48	26	63.4	260	230	1	0	0
DIBENZOTHIOPHENE	DIBENZO	0.7	46	33						
FLUORANTHENE	FLUORANT	0.91	54	45	600	5100	1300	2	0	1
FLUORENE	FLUORENE	1.3	50	32	19	540	120	3	0	0
NAPHTHALENE	NAPH	3.1	54	26	160	2100	230	0	0	0

		Minimum Detection Limit (MDL)	Frequency of concentration		Sediment Quality Guideline Values			Frequency of reported concentrations exceeded SQG values		
Chemical Name	**Abbreviation**		**Reported (detected)**	**Exceeded MDL**	**ERL**	**ERM**	**AET**	**> ERL**	**> ERM**	**> AET**
PYRENE	PYRENE	0.84	54	44	665	2600	2400	1	0	0
Total PAHs	T_PAHs				4022	44792		2	0	
Polychlorinated Biphenyls (PCB)										
PCB 101	PCB101	0.53	53	19						
PCB 105	PCB105	0.56	40	1						
PCB 118/108/149	PCB118	0.55	43	15						
PCB 126	PCB126	0.56	1	0						
PCB 128	PCB128	0.39	33	1						
PCB 138	PCB138	0.69	27	11						
PCB 153	PCB153	0.32	53	28						
PCB 170	PCB170	0.56	27	0						
PCB 18	PCB18	0.87	10	0						
PCB 180	PCB180	0.44	44	4						
PCB 187/182/159	PCB187	0.4	43	10						
PCB 195	PCB195	0.5	15	0						
PCB 206	PCB206	0.58	44	0						
PCB 209	PCB209	0.53	51	2						
PCB 28	PCB28	0.53	47	18						
PCB 44	PCB44	0.55	18	11						
PCB 52	PCB52	0.56	29	3						
PCB 66	PCB66	0.45	34	6						
PCB 77	PCB77	0.71	1	0						
PCB 8	PCB8	0.39	4	2						
Total PCBs	**T_PCB**				**22.7**	**180**	**130**	**0**	**0**	**0**

Chemical Name	Abbreviation	Minimum Detection Limit (MDL)	Frequency of concentration		Sediment Quality Guideline Values			Frequency of reported concentrations exceeded SQG values		
			Reported (detected)	Exceeded MDL	ERL	ERM	AET	> ERL	> ERM	> AET
Pesticides										
ALDRIN	ALDRIN	0.46	1	0			9.5			0
ALPHA-CHLORDANE	ALPHACHL	0.43	33	9						
ALPHA-ENDOSULFAN	ENDOSUL1	0.71	2	1						
BETA-ENDOSULFAN	ENDOSUL2	0.71	2	2						
DIELDRIN	DIELDRIN	0.43	40	5			1.9			0
ENDOSULFAN SULFATE	ENDOSUL	0.2	41	7						
ENDRIN	ENDRIN	0.43	0	0						
HEPTACHLOR	HEPTACHL	0.43	1	0			0.3			0
HEPTACHLOR-EPOXIDE	HEPTAEPO	0.43	25	1						
HEXACHLOROBENZENE	HEXACHL	0.21	6	1			6			0
LINDANE (GAMMA-BHC)	LINDANE	0.31	14	0			4.8			0
MIREX	MIREX	0.21	1	0						
TOXAPHENE	TOXAPHEN	28	0	0						
TRANS-NONACHLOR	TNONCHL	0.31	35	11						
DDT and Metabolites										
O,P'DDD	OPDDD	0.43	36	13						
O,P'DDE	OPDDE	0.71	1	0						
O,P'DDT	OPDDT	0.71	13	3						
P,P'DDD	PPDDD	1	41	4			16			0
P,P'DDE	PPDDE	0.71	52	24			9			0
P,P'DDT	PPDDT	1	27	1			12			0

Chemical Name	Abbreviation	Minimum Detection Limit (MDL)	Frequency of concentration		Sediment Quality Guideline Values			Frequency of reported concentrations exceeded SQG values		
			Reported (detected)	Exceeded MDL	ERL	ERM	AET	> ERL	> ERM	> AET
Total DDTs	Tot-DDT				1.58	46.1	11	23	0	1

Table 5.2.3 Correlation matrix for sediment texture and contaminant data based on 54 sediment samples collected for MCBP in 2000. The correlations were done using Pearson product-moment technique. Correlation analysis was conducted pairwise to include sample with missing parameter values. Values listed are Pearson correlation coefficients (r) (top value), sample size (in parenthesis), and *p*-value (in italic).

-		Water	siltclay	TOC	AL	SB	AS	CD	CR	CU
Water	***Correlation (Sample Size) PValue***		0.8644 (54) *0*	0.8403 (50) *0*	0.7735 (54) *0*	0.8459 (54) *0*	0.796 (54) *0*	0.7989 (54) *0*	0.8224 (54) *0*	0.7856 (54) *0*
siltclay	***Correlation***									
	(Sample Size)	0.8644 (54)		0.7295 (50)	0.9341 (54)	0.7925 (54)	0.9288 (54)	0.5931 (54)	0.9769 (54)	0.6742 (54)
	PValue	*0*		*0*	*0*	*0*	*0*	*0*	*0*	*0*
TOC	***Correlation***									
	(Sample Size)	0.8403 (50)	0.7295 (50)		0.6143 (50)	0.7201 (50)	0.6437 (50)	0.8535 (50)	0.7106 (50)	0.6859 (50)
	PValue	*0*	*0*		*0*	*0*	*0*	*0*	*0*	*0*
AL	***Correlation***			0.6143		0.7604	0.8792	0.4711	0.9499	0.572
	(Sample Size)	0.7735 (54)	0.9341 (54)	(50)		(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*		*0*	*0*	*0.0003*	*0*	*0*
SB	***Correlation***	0.8459	0.7925	0.7201	0.7604		0.8043	0.7206	0.7975	0.7674
	(Sample Size)	(54)	(54)	(50)	(54)		(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*		*0*	*0*	*0*	*0*
AS	***Correlation***	0.796	0.9288	0.6437	0.8792	0.8043		0.5493	0.9381	0.7261
	(Sample Size)	(54)	(54)	(50)	(54)	(54)		(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*		*0*	*0*	*0*
CD	***Correlation***	0.7989	0.5931	0.8535	0.4711	0.7206	0.5493		0.5621	0.7849
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)		(54)	(54)
	PValue	*0*	*0*	*0*	*0.0003*	*0*	*0*		*0*	*0*
CR	***Correlation***	0.8224	0.9769	0.7106	0.9499	0.7975	0.9381	0.5621		0.6657
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)		(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
CU	***Correlation***	0.7856	0.6742	0.6859	0.572	0.7674	0.7261	0.7849	0.6657	
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
FE	***Correlation***	0.8772	0.9832	0.725	0.952	0.8167	0.9432	0.6221	0.9745	0.6934
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PB	***Correlation***	0.9481	0.7819	0.8481	0.691	0.836	0.7193	0.8608	0.7414	0.8087
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
MN	***Correlation***	0.5584	0.8093	0.3901	0.8892	0.5776	0.8136	0.2374	0.836	0.4235
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0051*	*0*	*0*	*0*	*0.0839*	*0*	*0.0014*
HG	***Correlation***	0.8984	0.799	0.8303	0.7027	0.8668	0.7736	0.8703	0.7866	0.8937
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
NI	***Correlation***	0.8632	0.9804	0.6839	0.9526	0.8108	0.9408	0.5914	0.9744	0.701

-		Water	siltclay	TOC	AL	SB	AS	CD	CR	CU
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SE	***Correlation***	0.9346	0.7644	0.8759	0.6417	0.8127	0.7141	0.9245	0.7156	0.8257
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
AG	***Correlation***	0.6834	0.8078	0.5087	0.8725	0.67	0.7604	0.4445	0.8176	0.5704
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0002*	*0*	*0*	*0*	*0.0008*	*0*	*0*
SN	***Correlation***	0.9304	0.915	0.8196	0.8367	0.8889	0.8711	0.7942	0.9053	0.8417
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
ZN	***Correlation***	0.889	0.7653	0.7966	0.6493	0.7823	0.7277	0.9046	0.7219	0.8413
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
T_PAH	***Correlation***	0.3271	0.0885	0.3168	0.0305	0.2914	0.1122	0.256	0.096	0.4703
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0.0158*	*0.5245*	*0.025*	*0.8267*	*0.0326*	*0.4193*	*0.0617*	*0.4898*	*0.0003*
T_PCB	***Correlation***	0.7587	0.5548	0.7263	0.4219	0.71	0.5275	0.902	0.5076	0.8469
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0.0015*	*0*	*0*	*0*	*0.0001*	*0*
T_DDTs	***Correlation***	0.7275	0.4185	0.7315	0.2763	0.6506	0.3862	0.8372	0.3549	0.7307
	(Sample Size)	(54)	(54)	(50)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0.0016*	*0*	*0.0431*	*0*	*0.0039*	*0*	*0.0085*	*0*

Table 5.2.3 (cont.). Correlation matrix for sediment texture and contaminant data based on 54 sediment samples collected for MCBP in 2000. The correlations were done using Pearson product-moment technique. Correlation analysis was conducted pairwise to include sample with missing parameter values. Values listed are Pearson correlation coefficients (r) (top value), sample size (in parenthesis), and *p*-value (in italic).

-		FE	PB	MN	HG	NI	SE	AG	SN	ZN
Water	***Correlation***	0.8772	0.9481	0.5584	0.8984	0.8632	0.9346	0.6834	0.9304	0.889
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
siltclay	***Correlation***	0.9832	0.7819	0.8093	0.799	0.9804	0.7644	0.8078	0.915	0.7653
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
TOC	***Correlation***	0.725	0.8481	0.3901	0.8303	0.6839	0.8759	0.5087	0.8196	0.7966
	(Sample Size)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)	(50)
	PValue	*0*	*0*	*0.0051*	*0*	*0*	*0*	*0.0002*	*0*	*0*
AL	***Correlation***	0.952	0.691	0.8892	0.7027	0.9526	0.6417	0.8725	0.8367	0.6493
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
SB	***Correlation***	0.8167	0.836	0.5776	0.8668	0.8108	0.8127	0.67	0.8889	0.7823
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
AS	***Correlation***	0.9432	0.7193	0.8136	0.7736	0.9408	0.7141	0.7604	0.8711	0.7277
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*

-		FE	PB	MN	HG	NI	SE	AG	SN	ZN
CD	***Correlation***	0.6221	0.8608	0.2374	0.8703	0.5914	0.9245	0.4445	0.7942	0.9046
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0839*	*0*	*0*	*0*	*0.0008*	*0*	*0*
CR	***Correlation***	0.9745	0.7414	0.836	0.7866	0.9744	0.7156	0.8176	0.9053	0.7219
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
CU	***Correlation***	0.6934	0.8087	0.4235	0.8937	0.701	0.8257	0.5704	0.8417	0.8413
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0014*	*0*	*0*	*0*	*0*	*0*	*0*
FE	***Correlation***		0.7977	0.8399	0.8091	0.9919	0.7813	0.8318	0.9226	0.7876
	(Sample Size)		(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue		*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
PB	***Correlation***	0.7977		0.4654	0.9083	0.7807	0.9226	0.6357	0.9255	0.9268
	(Sample Size)	(54)		(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*		*0.0004*	*0*	*0*	*0*	*0*	*0*	*0*
MN	***Correlation***	0.8399	0.4654		0.4844	0.8407	0.399	0.8389	0.659	0.471
	(Sample Size)	(54)	(54)		(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0.0004*		*0.0002*	*0*	*0.0028*	*0*	*0*	*0.0003*
HG	***Correlation***	0.8091	0.9083	0.4844		0.8056	0.9176	0.666	0.9513	0.9016
	(Sample Size)	(54)	(54)	(54)		(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0002*		*0*	*0*	*0*	*0*	*0*
NI	***Correlation***	0.9919	0.7807	0.8407	0.8056		0.7609	0.8317	0.9178	0.7727
	(Sample Size)	(54)	(54)	(54)	(54)		(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0*	*0*		*0*	*0*	*0*	*0*
SE	***Correlation***	0.7813	0.9226	0.399	0.9176	0.7609		0.5505	0.8906	0.9113
	(Sample Size)	(54)	(54)	(54)	(54)	(54)		(54)	(54)	(54)
	PValue	*0*	*0*	*0.0028*	*0*	*0*		*0*	*0*	*0*
AG	***Correlation***	0.8318	0.6357	0.8389	0.666	0.8317	0.5505		0.7762	0.6355
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)		(54)	(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*		*0*	*0*
SN	***Correlation***	0.9226	0.9255	0.659	0.9513	0.9178	0.8906	0.7762		0.8986
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)		(54)
	PValue	*0*	*0*	*0*	*0*	*0*	*0*	*0*		*0*
ZN	***Correlation***	0.7876	0.9268	0.471	0.9016	0.7727	0.9113	0.6355	0.8986	
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	
	PValue	*0*	*0*	*0.0003*	*0*	*0*	*0*	*0*	*0*	
T_PAH	***Correlation***	0.0832	0.4286	0.0707	0.3455	0.0939	0.254	0.0445	0.2756	0.2172
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0.5495*	*0.0012*	*0.6112*	*0.0105*	*0.4995*	*0.0638*	*0.7491*	*0.0437*	*0.1147*
T_PCB	***Correlation***	0.5686	0.8422	0.2287	0.8617	0.5504	0.8342	0.4737	0.7802	0.8734
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0*	*0*	*0.0962*	*0*	*0*	*0*	*0.0003*	*0*	*0*
T_DDTs	***Correlation***	0.4253	0.8226	0.0328	0.763	0.3983	0.793	0.2911	0.6676	0.7486
	(Sample Size)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)	(54)
	PValue	*0.0013*	*0*	*0.8136*	*0*	*0.0029*	*0*	*0.0327*	*0*	*0*

Table 5.2.4**.** Summary of physical and chemical data for sediment samples collected in 2000 for MCBP. Clay content was calculated as % Clay=0.308871(% Siltclay)+0.055768(%Water). Excess total carbon (TOC) was calculated as the difference between measured TOC and predicted TOC, where predicted TOC= 0.0448 * %Clay-0.079. Both equations are based on sediment data from Wells and others (1999). Frequency of reported contaminant concentrations exceeding mean detection limit (MDL), ERL, ERM and AET limits, and AET Quotient are listed for each sample.

						Number of sediment contaminants				**Number of sediment contaminants exceeding threshold values**			**Mean AET Quotient**
						Metals		**Organic**					
STA	**BASIN**	**% Water**	**Clay**	**% TOC**	**Excess TOC**	**Total**	**> MDL**	**Total**	**> MDL**	**ERL**	**ERM**	**AET**	
MD-CB-01	W.OC Harbor	64.00	27.87	1.64	0.39	15	12	49	39	**12**	**0**	**2**	**0.34**
MD-CB-02	Sinepuxent	23.53	4.15	0.31	0.12	15	10	36	3	**0**	**0**	**0**	**0.05**
MD-CB-03	NewportBay	20.50	2.54	0.18	0.07	12	6	27	1	**0**	**0**	**0**	**0.02**
MD-CB-04	NewportBay	69.67	31.95			15	12	43	21	**3**	**0**	**1**	**0.14**
MD-CB-05	Chincoteague	53.72	31.14			15	12	44	16	**2**	**0**	**2**	**0.13**
MD-CB-06	Chincoteague	28.16	6.08	0.26	-0.01	15	8	37	2	**0**	**0**	**0**	**0.05**
MD-CB-07	JohnsonBay	56.18	30.63	1.4	0.03	15	12	40	12	**2**	**0**	**1**	**0.12**
MD-CB-08	ChincoteagueBay_VA	47.48	23.66	1.33	0.27	15	12	42	13	**2**	**0**	**1**	**0.11**
MD-CB-09	ChincoteagueBay_VA	45.39	20.52	0.88	-0.04	15	12	40	9	**1**	**0**	**1**	**0.10**
MD-CB-10	ChincoteagueBay_VA	54.15	27.86	1.23	-0.02	15	12	44	11	**2**	**0**	**1**	**0.12**
MD-CB-11	ChincoteagueBay_VA	18.64	1.49	0.06	-0.01	13	7	27	3	**0**	**0**	**0**	**0.04**
MD-CB-12	ChincoteagueBay_VA	18.38	1.78	0.32	0.24	11	7	30	1	**0**	**0**	**0**	**0.04**
MD-CB-13	ChincoteagueBay_VA	17.09	1.83	0.13	0.05	12	6	27	1	**0**	**0**	**0**	**0.03**
MD-CB-14	JohnsonBay	46.31	23.23	1.55	0.51	15	12	40	10	**1**	**0**	**1**	**0.10**
MD-CB-15	Chincoteague	22.69	4.05	0.12	-0.06	14	8	32	3	**0**	**0**	**0**	**0.04**
MD-CB-16	Sinepuxent	38.66	14.09	0.7	0.07	15	11	41	14	**0**	**0**	**1**	**0.08**
MD-CB-17	Sinepuxent	17.75	1.29	0.13	0.07	11	5	19	2	**1**	**0**	**0**	**0.03**
MD-CB-18	Sinepuxent	12.97	0.97	0.08	0.04	10	5	23	0	**0**	**0**	**0**	**0.01**
MD-CB-19	BishipvilleProng	73.91	25.55	3.25	2.11	15	13	49	35	**4**	**0**	**0**	**0.20**
MD-CB-20	BishipvilleProng	42.99	4.61	0.48	0.27	15	10	44	24	**2**	**0**	**0**	**0.08**
MD-CB-21	HerringCreek	76.11	32.07	4.69	3.25	15	13	46	32	**5**	**0**	**1**	**0.22**
MD-CB-22	ShingleLdg	76.51	32.95			15	13	44	30	**5**	**0**	**2**	**0.19**
MD-CB-23	ShingleLdg	79.16	33.03	6.6	5.12	15	13	47	31	**5**	**0**	**1**	**0.20**
MD-CB-24	TurvilleCreek	68.17	28.47	0.55	-0.73	15	12	49	32	**3**	**0**	**1**	**0.18**
MD-CB-25	TurvilleCreek	41.20	9.00	0.23	-0.17	15	11	44	23	**1**	**0**	**0**	**0.11**
MD-CB-26	BishipvilleProng	83.38	30.45	5.69	4.33	15	13	49	40	**5**	**0**	**2**	**0.24**
MD-CB-27	St.MartinR	58.27	32.06	3	1.56	15	12	47	26	**3**	**0**	**2**	**0.17**

STA	BASIN	% Water	Clay	% TOC	Excess TOC	**Number of sediment contaminants**				**Number of sediment contaminants exceeding threshold values**			**Mean AET Quotient**
						Metals		**Organic**					
						Total	**> MDL**	**Total**	**> MDL**	**ERL**	**ERM**	**AET**	
MD-CB-28	St.MartinR	57.14	32.76	2.88	1.41	15	12	47	25	**3**	**0**	**2**	**0.16**
MD-CB-29	St.MartinR	65.91	33.63	4.97	3.46	15	13	46	30	**4**	**0**	**3**	**0.19**
MD-CB-30	St.MartinR	73.18	32.13	6.52	5.08	15	13	48	34	**5**	**0**	**2**	**0.21**
MD-CB-31	BishipvilleProng	19.89	1.56	0.06		10	7	21	0	**0**	**0**	**0**	**0.03**
MD-CB-32	AyersCreek	26.62	2.29	0.33	0.23	13	5	43	22	**1**	**0**	**0**	**0.07**
MD-CB-33	NewportCreek	57.36	12.59	4.09	3.53	15	11	44	28	**10**	**0**	**1**	**0.29**
MD-CB-34	NewportCreek	75.33	15.92	3.28	2.57	15	11	35	28	**3**	**0**	**0**	**0.16**
MD-CB-35	TrappeCreek	21.30	2.03	0.19	0.10	13	8	46	11	**0**	**0**	**0**	**0.04**
MD-CB-36	Chincoteague	37.72	13.10	0.69	0.10	15	10	42	9	**0**	**0**	**1**	**0.08**
MD-CB-37	NewportBay	52.08	32.10	1.71	0.27	15	12	45	17	**2**	**0**	**1**	**0.13**
MD-CB-38	NewportBay	56.74	31.90	2.29	0.86	15	12	44	14	**1**	**0**	**1**	**0.12**
MD-CB-39	Isle of Wight	14.28	1.04	0.05	0.00	9	5	11	0	**0**	**0**	**0**	**0.01**
MD-CB-40	Isle of Wight	16.01	1.26	0.09	0.03	12	6	15	0	**0**	**0**	**0**	**0.02**
MD-CB-41	Isle of Wight	43.85	20.04	3.72	2.82	15	12	48	17	**0**	**0**	**1**	**0.11**
MD-CB-42	Isle of Wight	21.85	4.10	0.09	-0.09	14	7	39	7	**0**	**0**	**0**	**0.04**
MD-CB-43	Assawoman	45.90	24.69	1.55	0.44	15	12	47	19	**1**	**0**	**1**	**0.12**
MD-CB-44	Greys Creek	52.85	32.94	3.2	1.72	15	12	43	23	**3**	**0**	**2**	**0.17**
MD-CB-45	Assawoman	37.28	28.86			15	12	45	19	**2**	**0**	**1**	**0.13**
MD-CB-46	TurvilleCreek	64.11	29.76	2.73	1.40	15	12	46	22	**2**	**0**	**2**	**0.14**
MD-CB-47	ManklinCreek	28.22	6.58	0.25	-0.04	15	10	42	7	**0**	**0**	**0**	**0.04**
MD-CB-48	Greys Creek	21.29	3.66	0.25	0.09	15	7	47	26	**1**	**0**	**0**	**0.06**
MD-CB-49	Roys Creek	65.66	29.39	3.77	2.45	15	12	42	26	**3**	**0**	**2**	**0.17**
MD-CB-50	The Ditch	19.95	2.35	0.16	0.05	11	5	35	2	**0**	**0**	**0**	**0.02**
MD-CB-51	Chincoteague	31.66	8.21	0.22	-0.15	15	9	40	2	**0**	**0**	**1**	**0.06**
MD-CB-52	Chincoteague	21.75	3.33	0.22	0.07	12	6	28	0	**0**	**0**	**0**	**0.03**
MD-CB-53	Chincoteague	55.45	30.23	1.26	-0.09	15	12	46	16	**1**	**0**	**1**	**0.12**
MD-CB-54	Chincoteague	29.82	9.42	0.29	-0.13	15	9	40	3	**0**	**0**	**1**	**0.07**

Chapter 5.3

Ambient toxicity of sediments from the Maryland Coastal Bays

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Abstract

Overall, the Coastal Bays sediments show little evidence of toxicity. This is consistent with the sediment chemistry results that there were no exceedances of ER-M values. It is important to note that dead-end canals were not sampled; other studies have shown these areas to have more toxicity due to leachate from pilings and runoff from development (Challiou et. al. 1996).

Introduction

Ambient toxicity is a bioassay that is used to evaluate potential toxicity by exposing an indicator organism to surficial sediment samples and measuring mortality and/or growth over time. The survival rate of the amphipod *Ampelisca abdita* is measured in the sediments in a 10-day assay and compared to a control sample, which uses sediment from a relatively clean reference site. Samples differing significantly from the control were considered to have significant toxicity.

There had never been any ambient toxicity study done on the Maryland Coastal Bays before 1999. During the summer of 1999, DNR conducted a pilot study comparing two sediment toxicity bioassays from five stations in the Maryland's Coastal Bays (Figure 5.3.1). Comparison was made with sediment from a control site, Fishing Bay with Patuxent River sand (25%). Two different amphipod species were used; *Leptocheirus plumulosus* and *Ampelisca abdita* to determine which organism was a better indicator in the coastal bays (*L. plumulosus* is used in Chesapeake Bay monitoring and *A abdita* is used for EMAP monitoring).

Ampelisca abdita is a tube-dwelling amphipod found mainly in protected areas from the low intertidal zone depths to 60m. It ranges from central Maine to south-central Florida and the Eastern Gulf of Mexico and has also been introduced into San Francisco Bay. It has been reported in waters, which range from fully marine to 10 parts per thousand salinities and inhabits sediments from fine sand to mud and silt without shell, although it may also be found in relatively coarser sediments with a sizable fine component. *A. abdita* may be collected throughout the year. For these reasons, this is the methodology used by USEPA for national assessments.

The 10-day survival and growth *Leptocheirus plumulosus* test (and subsequently 28-day survival, growth and reproduction test) was also used to assess the toxicity of the coastal bays stations because this is the technique used in Maryland and the Chesapeake Bay. *Leptocheirus plumulosus* is an estuarine amphipod found in fine-grained clayey-silt sediments with moderate organic carbon content along the East coast. It also inhabits areas with wide range of salinities (0-33ppt). Although *Ampelisca* has a similar salinity range, it slightly differs from *Leptocheirus* in temperature range. *Ampelisca* has slightly colder test temperature requirement.

Since that study was never published, the results are presented in this document.

Data Sets

Environmental Monitoring and Assessment Program, EMAP

EMAP: Joint Assessment of the Maryland and Delaware Coastal Bays 1996

EMAP: Mid-Atlantic Integrated Assessment, MAIA 1997-98

July 1999 Preliminary DNR study – tested new methods in preparation for August Pilot study.

August 1999 Pilot DNR study – results reported here from two different amphipod toxicity tests (*Leptocheirus*, and *Ampelisca*).

Primarily focused on data from the National Coastal Assessment (NCA) Surveys in 2000 and 2001 at 54 stations

Management Objective: none

***Draft* Toxicity Indicator:** Statistical difference from control sample
(percent survival compared to control)

Data Analyses

Data analyses primarily focused on the NCA 2000 and 2001 data. The amphipod, *Ampelisca*, was used to test for toxicity (5 reps). Reference sediment for the bioassay was collected from the Intercoastal Waterway, near the Florida-Alabama line. This sediment is a silty mud, relatively clean of chemical contaminants.

The results presented herein focus first on an unpublished pilot study conducted by DNR in the coastal bays during August 1999 (and the associated preliminary study to the pilot project conducted in July 1999) and second on the recent status analyses using 2000 and 2001 National Coastal Assessment survey results.

A. 1999 Pilot DNR study:

Pilot Study Methods: Each amphipod (*Ampelisca abdita* and *Leptocheirus plumulosus*) was subjected to a 10-day survival and growth bioassay. End-points employed were survival and growth. *Leptocheirus* was subjected to an additional 28-day test for survival, growth and reproduction. The bioassay tests were done at 25°C in the temperature controlled Aquatic Toxicity Testing Laboratory at the University of Maryland Chesapeake Biological Laboratory at Solomons, Maryland in July and August of 1999.

Grain size analysis and chemical analyses for organic contaminants and mercury were also conducted on these sediments.

Both amphipods tests were performed in 25 ‰ salinity. They differed in their food sources: *Leptocheirus* was fed every three days with ground Tetramin™ while *Ampelisca* was fed with a mixture of diatoms Tahiti *Isochrysis* and *Skeletonema* daily.

Station 1 was located on the upstream side of the St. Martin River; Station 2 was at the mouth of the same River. Station 3 was where Turville and Herring creeks drain; Station 4 is located at Newport Bay near Sinepuxent Neck; and, Station 5 is located downstream from the Public Landing.

Control sediment was the sediment used as culture sediment for *Leptocheirus plumulosus*. The sediment was collected from a clean site in Fishing Bay at the mouth of the Transquaking River. The reference sand was collected at the mouth of the Patuxent River. *L. plumulosus* had been known to do better in sediment with 25% sand.

Results of Preliminary Bioassays (July 1999): Survival of the marine amphipod, *Ampelisca abdita*, was low during the preliminary bioassay test in July 1999. The control sediment only had 30% survival, which probably makes this test invalid. Station 1 had the lowest at 15%, while Station 2 ha the highest at 65%. Stations 3, 4 and 5 had 40% survival (Figure 5.3.2). The low survival could be attributed to stress during shipment and/or shortness of the salinity acclimation time (from 32‰ down to 25‰).

Growth of surviving *Ampelisca abdita* was between 49 - 96% over the bioassay period. Over the same period, amphipods in the control sediment increased 57% from the initial size. Station 3 had the highest growth at 96% while Station 5 had the lowest at 49% (Figure 5.3.2).

The number of animals used during the test (10 animals per replicate) was not ideal for this test, and we recommend at least 20 per replicate in future tests. *Ampelisca abdita* was recommended to be the test organism of choice for the Coastal Bays 2000 project.

Results of 1999 Pilot Study (August): *Ampelisca abdita* survival varied between 52 and 75%. The survival of the animals in the Control sediment was 72.5%, still a little lower than ideal survival (at, say, 75-80%). Stations 1 and 4 had the lowest survival at 52.5%

and Station 2 had the highest at 75% (figure 5.3.4). Survival, however, was low for the test to be valid. The surviving *Ampelisca abdita* increased a lot in size. Test animals the Control sediment increased 110%. Station 3 had the highest increase at 366% while the Station 4 had the lowest at 130%. The increase in sizes, however, did not vary significantly from those in the Control (Figure 3).

Ampelisca survival was somewhat low: Control only had 75% survival. Station 1 had the lowest at 63% and Station 3 had the highest at 80%. There was no significant difference in amphipod survival between the *L. plumulosus* in the Control sediment and those in the 5 sampling stations in the Coastal Bays. Low survival may have been the effect of the short salinity acclimation (from 15‰ to 25‰) time. Acclimatization should be at least a couple of months prior to bioassay tests.

The growth of *Ampelisca* varied between 184 and 368%. The size of the animals in the control sediment increased 278% in size from their initial weight. Station 1 had the highest increase at 368% while Station 4 had the lowest at 184%. This test, however, was only a 10-day test instead of the usual 28 days.

Survival of *Leptocheirus plumulosus* varied between 100 and 85 % after the 28-day exposure to the Control and the coastal bays sediments. The survival of the animals in the Control sediment was 96%. Station 3 had the highest survival at 100% while Station 5 had the lowest at 85%. There was no significant difference between survival of the Control sediment and the different Coastal Bays stations.

Percentage increase in size of *Leptocheirus* from most of the test stations was high compared to the control. *L. plumulosus* exposed to the sediment from Station 5 had the lowest increase in size (at 720%) of all the test animals. The amphipods in the Control sediment had the highest increase at 2400%, followed by those in Station 1 at 1962% and Station 2 at 1145%. The amphipods exposed to sediments from stations 3 and 4 had similar percentage increase in size (figure 5.3.5). *Leptocheirus* exposed to the sediment from Station 1 grew similarly to those in the Control sediment. Those exposed to the sediments from stations 2, 3 and 4 were significantly smaller ($p = 0.05$) than those in the Control while the animals in the sediment from Station 5 were also smaller ($p = 0.01$) than those in the Control.

Leptocheirus reproduction results were somewhat a similar to the percentage increases in size. The amphipods in the Station 1 sediment had higher number of progeny than those in the Control sediment. The number of progeny gets gradually lower from Station 2 down to Station 5. The number of young amphipods exposed to sediments from stations 4 and 5 were significantly different than the Control. Could the suggestion that some test animals produce more young when there is more environmental impact (to protect their population) be true?

<u>Pilot Study Summary</u>: The results of the two tests in the summer of 1999, using *Ampelisca abdita* was not consistent, maybe due to the fact that the animals did not have enough time to acclimate to the lower salinity, 25‰ (as compared to their natural

environment of around 32‰), they were subjected to during the bioassay tests. Maybe the temperature in the laboratory, 25°C ±2°C was higher than its natural environment. *Ampelisca* may have lower temperature requirement compared to *Leptocheirus*. These two environmental factors have to be considered should there be another opportunity to use *Ampelisca* as test animals for bioassay tests again.

On the other hand the *Leptocheirus plumulosus* were cultured in house, but they were subjected to somewhat similar acclimation to *Ampelisca*, the salinities were adjusted higher from their culture salinity of 15‰ to 25‰, in the same amount of time that the other amphipods were subjected to. They also had to adjust to the testing laboratory temperature which was 25°C ±2°C, from their culture laboratory of about 20°±2°C, however, this temperature change may not have been as high as what *Ampelisca* had been subjected to.

The results of the preliminary and the main (28-day) *Leptocheirus* tests were similar in the percentage survival of the test animals. The percentage increase in size during the 10-day test did not have a similar trend compared to the 28-day test. The results of both the growth (measured in terms of percentage increase in size) and reproduction (measured in terms of the number of juveniles) during the 28-day *Leptocheirus* test showed the same trend. Both were highest at Station 1, even higher than the Control in the number of juveniles; then both measures had a decreasing trend from stations 2 to 5.

Grain size, in particular clay content, has been shown to be related to sediment quality (see chapter on Total Organic Carbon by Wells). Results of grain size analysis for the sampling sites are given in Table 5.3.1.

Table 5.3.1: Results of grain size analyses done by the Maryland Geological Survey Team. (July samples were from the DNR preliminary study and August samples were from the DNR Pilot Study).

	Stations	**% H_2O**	**Bulk Density**	**% Gravel**	**% Sand**	**% Silt**	**% Clay**	**Shepard's Classification**
July 9, 1999 samples	Control	68.09	1.25	0.00	16.33	50.97	32.70	Clayey Silt
	Station 1	73.87	1.20	0.00	2.20	34.53	63.27	Silty Clay
	Station 2	57.61	1.37	0.00	2.12	59.01	38.87	Clayey Silt
	Station 3	56.61	1.38	0.00	3.56	42.84	32.46	Sand-Silt-Clay
	Station 4	57.36	1.37	0.00	24.70	70.41	26.03	Clayey Silt
	Station 5	51.05	1.45	0.00	51.60	26.96	21.44	Sand-Silt-Clay
August 1999 samples	Control	72.63	1.21	0.00	8.38	54.95	36.68	Clayey Silt
	Sand Ref*	18.77	2.06	5.94	92.72	1.34	0.00	Sand
	Station 1	65.31	1.28	0.00	4.41	36.82	58.77	Silty Clay
	Station 2	52.58	1.43	0.00	2.68	60.83	36.49	Clayey Silt
	Station 3	55.02	1.40	0.00	23.88	47.39	28.73	Sand-Silt-Clay
	Station 4	51.16	1.45	0.00	10.34	68.36	21.30	Clayey Silt
	Station 5	57.37	1.37	0.00	14.01	43.17	43.82	Clayey Silt

*Patuxent River sand.

Chemical Analyses conducted by the State Chemist Laboratory at the Maryland Department of Agriculture revealed fluoranthene, phenanthrene, benzo(a)pyrene, benz(e)acephenanthrylene an 1,2:5,6-dibenzanthracene were detected in sediments in most of the 5 stations, but not in the control (Fishing Bay) sediment (Figure 5.3.6). Mercury was found in sediments from all stations, including the control (Fishing Bay) sediment (Figure 5.3.7).

The presence of organic contaminants and mercury in the sediments showed somewhat similar trend to the *Leptocheirus plumulosus* test, especially the tests for percentage increase in size and the number of progeny. However, there were not enough samples and tests to make any conclusions.

B. Status of Sediment Toxicity (August 2000 and 2001)

The following results refer to 10 day *Ampelisca* tests conducted as part of the National Coastal Assessment survey (bioassays done by Federal subcontractor).

Assawoman Bay – no toxicity detected at the 7 sites sampled (Figure 5.3.8).

St. Martin River – no toxicity detected at the 10 sites sampled (Figure 5.3.8).

Isle of Wight

In 2000, one site in the open bay showed evidence of toxicity; however, no toxicity was detected at same site in 2001 (Figure 5.3.8). Companion sediment chemistry data did not provide insight into what caused these results. Remaining six sites passed toxicity test.

Sinepuxent – No toxicity was detected at the 5 sites sampled in 2000 and 2001 (Figure 5.3.8).

Newport – No toxicity was detected at the 7 sites sampled in 2000 and 2001 (Figure 5.3.8).

Chincoteague

In 2000, one site at the north end of Chincoteague Island in Virginia (Wildcat Point) showed evidence of toxicity; however, no toxicity was detected at the same site in 2001 (Figure 5.3.8). Companion sediment chemistry data did not provide insight into what caused these results. Remaining 15 sites passed toxicity test in both years.

Summary

Overall, the Coastal Bays sediments show little evidence of toxicity. This is consistent with the sediment chemistry results that there were no exceedances of ER-M values (see previous chapter on Sediment Chemistry). No explanation for why the two sites that failed in 2000 but passed in 2001. It is important to note that dead-end canals were not sampled; other studies have shown these areas to have more toxicity due to leachate from pilings and runoff from development (Challiou et. al. 1996).

A pilot study conducted by DNR in 1999 showed that the amphipod test used for this status analysis is not as sensitive as other species. Recommend future testing for toxicity using other methods or trying to use more *Ampelisca*, say at least 20 per replicate, to see whether the animal is really a good indicator of an environmental impact. *Leptocheirus*, however, shows a lot of promise, even if it is not a strictly marine animal. It appears to be more sensitive to low levels of chemical contaminants. A longer acclimation time of approximately a month for *Ampelisca* (from 32 to 25 ‰) and a couple of months for *Leptocheirus* (from 15‰ to 25‰ might also prove beneficial. Recommend testing other 'pristine' sediment for future Control Sediment should be made. Maryland Geologic Survey suggested a couple of places in the Choptank River to collect from according to their metal content monitoring of different areas of the bay.

Acknowledgements

A special thanks to the crews that helped collect the field samples, including Fred Kelly and Brian Sturgis.

References

Challiou, J.C., Weisberg, F.W., Kutz, F.W., DeMoss, T.E., Mangiaracina, L., Magnien, R., Eskin, R., Maxted, J., Price, K., and Summers, J.K., 1996, Assessment of the ecological condition of the Delaware and Maryland Coastal Bays, U.S. Environmental Protection Agency, National Human and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL., EPA/620/R-96/004.

USEPA 2002. Mid-Atlantic Integrated Assessment 1997-98 Summary Report, EPA/620/R-02/003. U.S. Environmental Protection Agency, Atlantic Ecology Division, Narragansett, RI.

Figure 5.3.1: Map showing sites of sediment collection for 1999 pilot ambient toxicity testing.

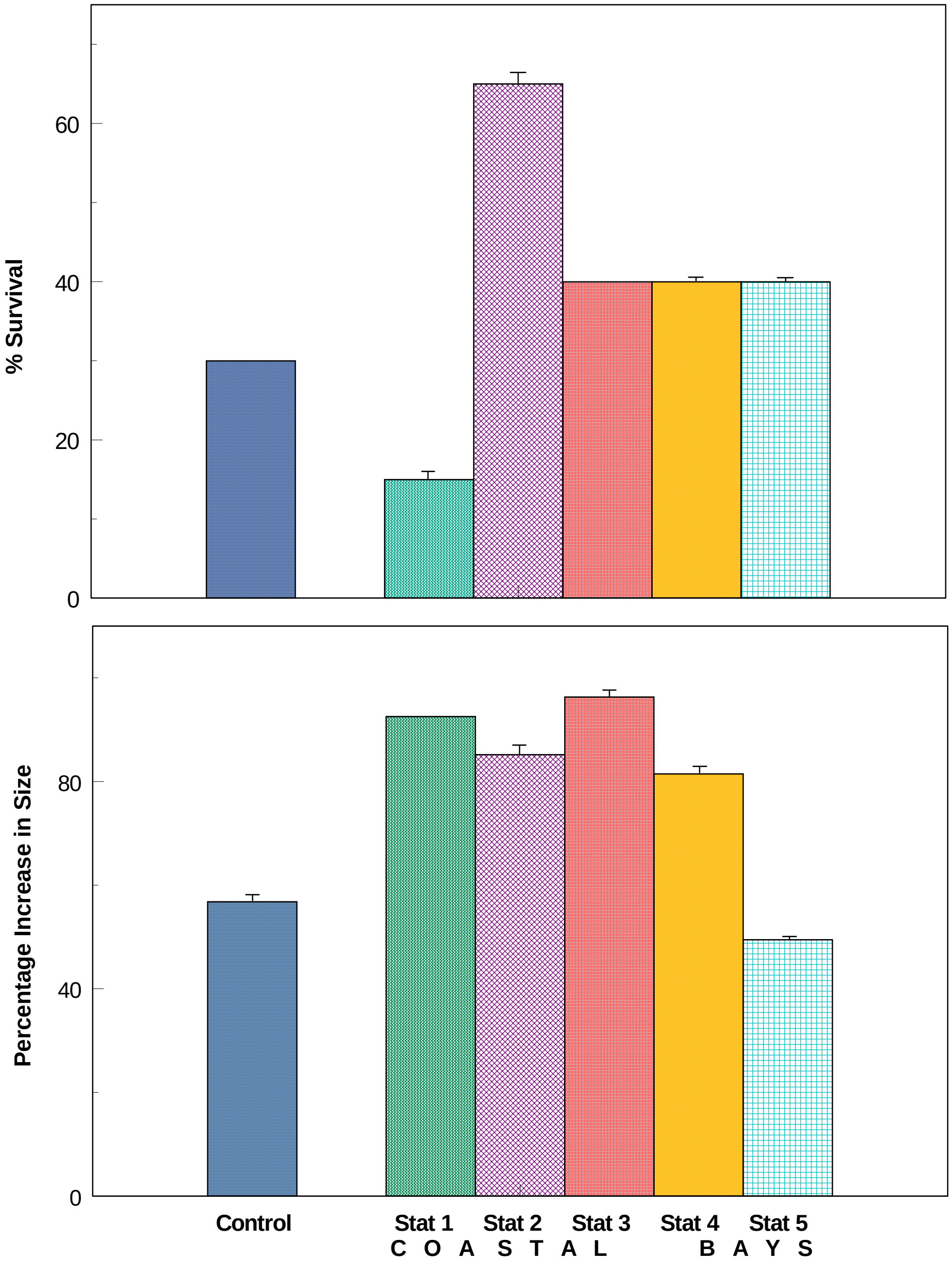

Figure 5.3.2: Preliminary Study (July 1999) bioassay using *Ampelisca abdita* percent survival and growth (percentage increase in size) after ten-day exposure to Coastal Bays sediments in July 1999. Control sediment was from Fishing Bay.

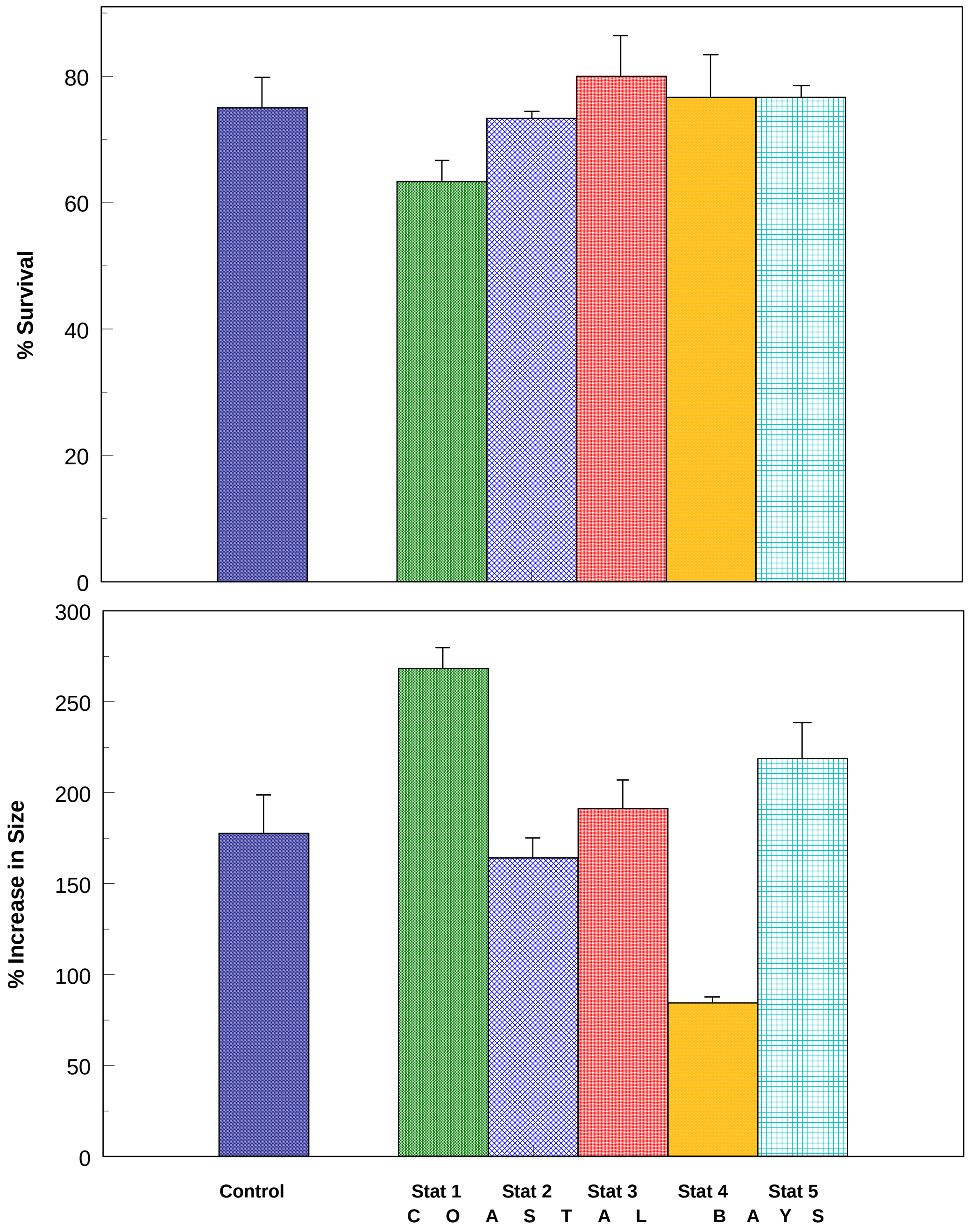

Figure 5.3.3: Preliminary DNR Study (July 1999) bioassay study using *Leptocheirus plumulosus* % survival and growth (% increase in size) after ten-day exposure to Coastal Bays sediments in 1999. Control sediment was from Fishing Bay.

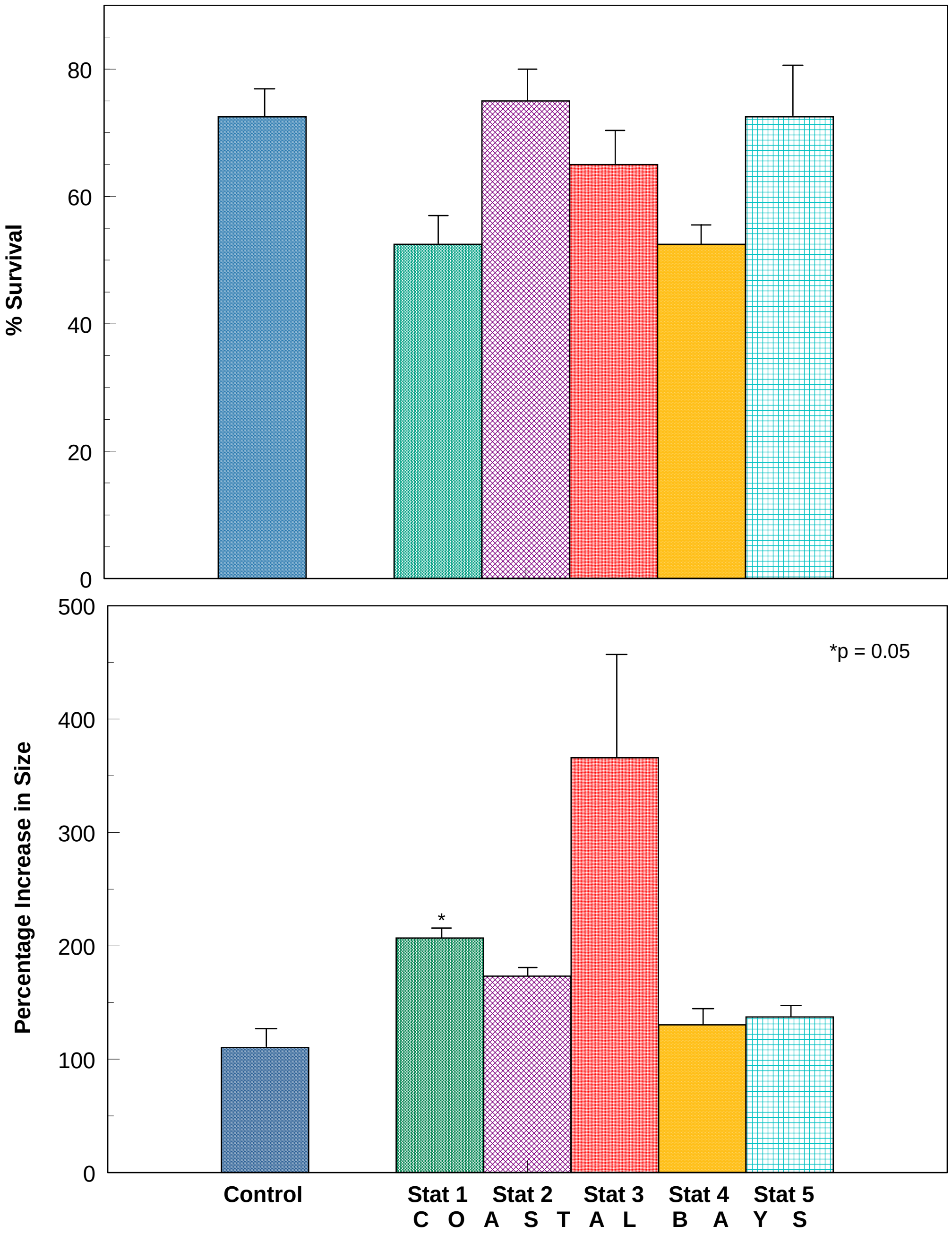

Figure 5.3.4: *Ampelisca abdita* % survival and growth (percentage increase in size) after ten-day exposure to Coastal Bays sediments in August 1999 (DNR Pilot Study). Control sediment was from Fishing Bay.

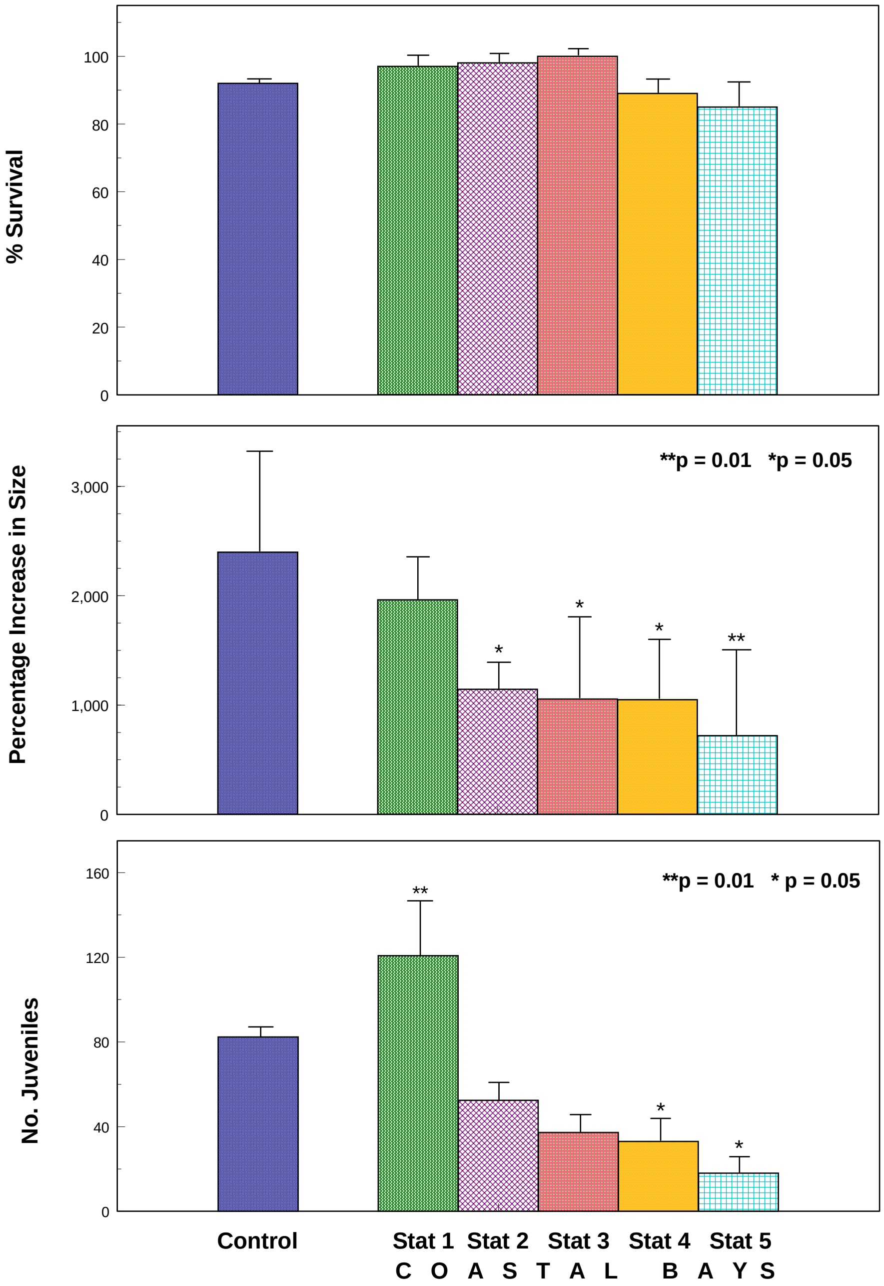

Figure 5.3.5: *Leptocheirus plumulosus* % survival, percentage increase in size and reproduction after 28-day exposure to Coastal Bays sediments in August1999 (DNR Pilot Study. Control sediment was from Fishing Bay.

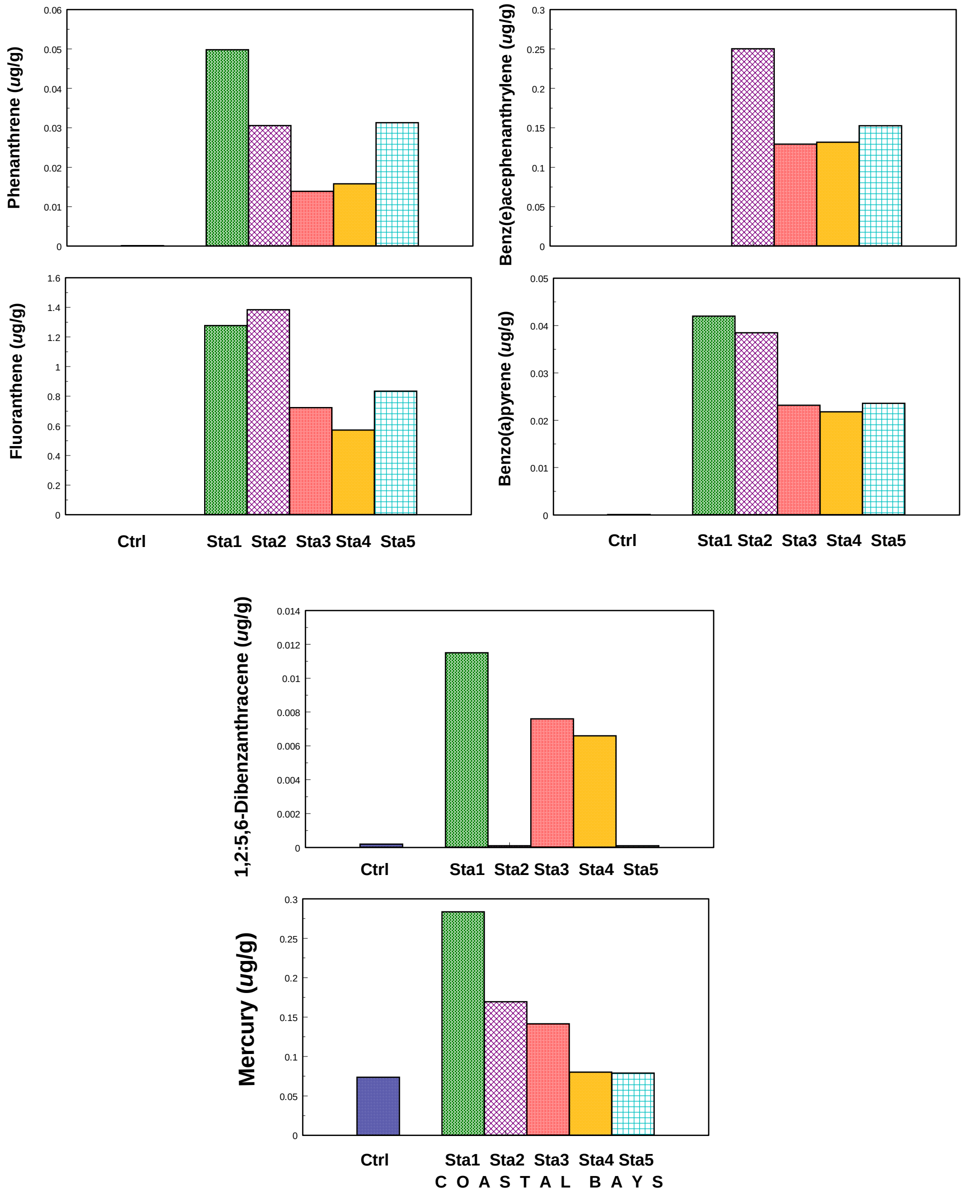

Figure 5.3.6: A comparison of selected organic contaminant and mercury concentrations between Coastal Bays and control (Fishing Bay) sediments. All concentrations are in micrograms per gram sediment (*u*g/g). a.) Phenanthrene b.) Benz(*e*)ancephenanthrylene c.) Fluoranthene d.) Benzo(*a*)pyrene e.) 1,2:5,6-Dibenzanthracene f.) Mercury.

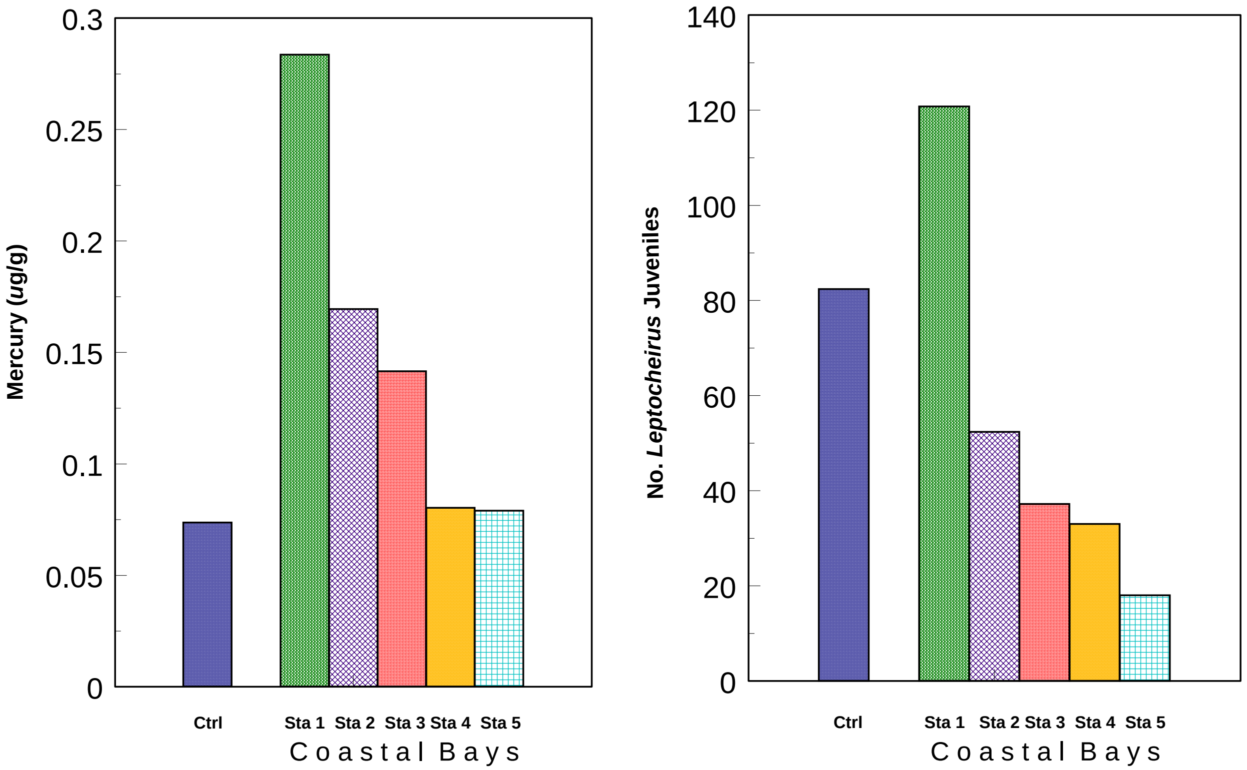

Figure 5.3.7: a.) Sediment mercury concentration from each Coastal Bays station and the control (Fishing Bay). b.) Number of juvenile *Leptocheirus plumulosus* found in sediments from each Coastal Bays station and the control (Fishing Bay).

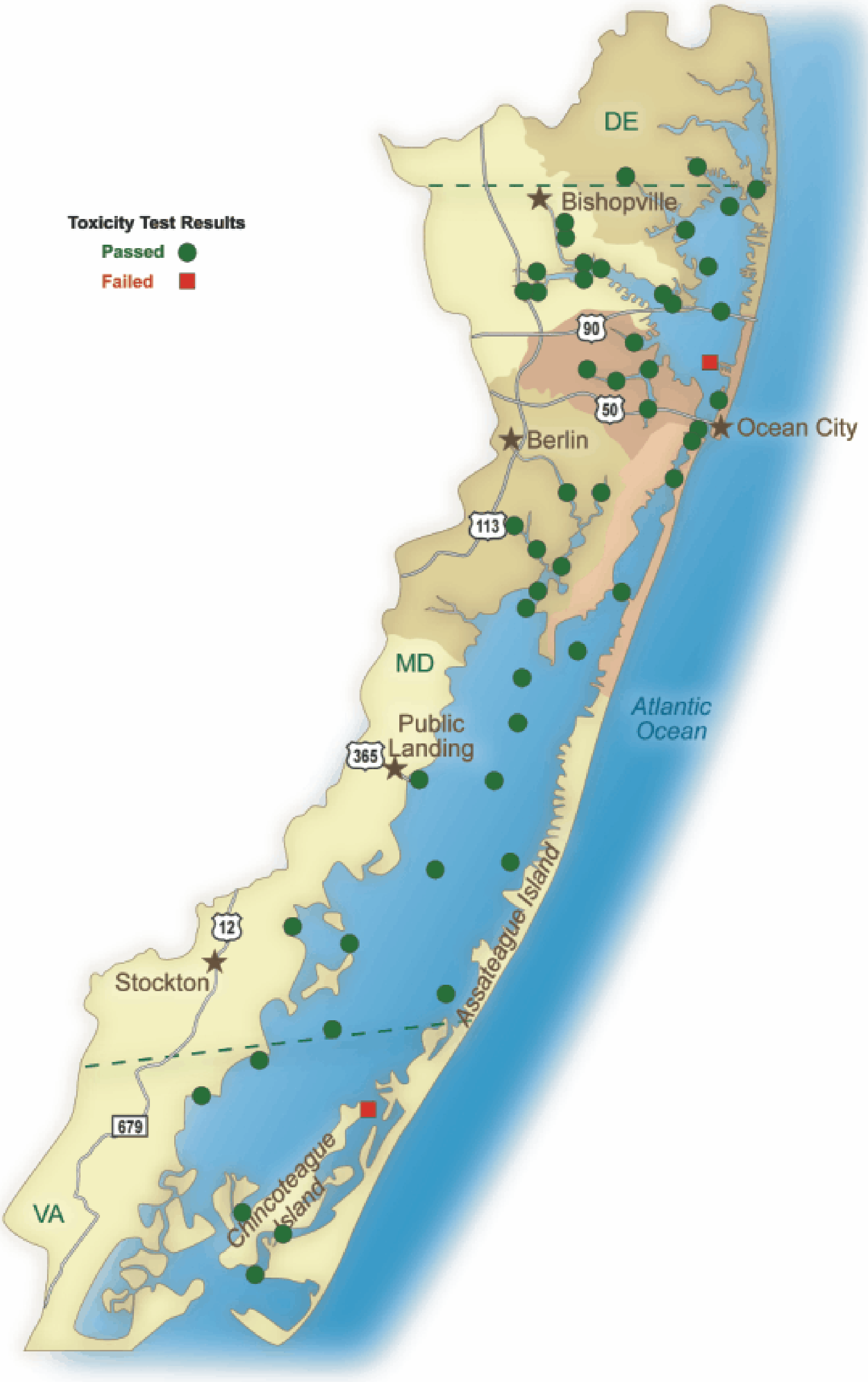

Figure 5.3.8: Map showing results of ambient toxicity tests conducted on samples collected in 2000 and 2001 (if failed either year).

Section 6: Habitat condition in the Maryland Coastal Bays

General Introduction

Key habitats such as seagrass beds, wetlands, and natural shorelines are necessary to ensure the health of Coastal Bays fish and shellfish populations. Seagrasses are an important resource in the Coastal Bays, improving water quality, providing habitat for fish and shellfish and food for aquatic species and water birds. Wetlands are necessary to maintain habitat for waterfowl and fish, buffer coastal storms, absorb flood waters, and maintain adequate water quality for all Coastal Bays inhabitants. Changes to shorelines (bulkheading, rip-rap) threaten many fish and shellfish species as well as diamond back terrapins, shorebirds, and horseshoe crabs, which rely on the Coastal Bays for all or part of their life cycle. Macroalgal flora can be an important habitat, especially in areas where no other structure (such as seagrass beds) exists. The following chapters summarize recent monitoring analyses of five Coastal Bays habitat indicators.

Chapter 6.1

Seagrass abundance and habitat criteria in the Maryland Coastal Bays

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Abstract

Seagrasses have been increasing annually since monitoring began in 1986. General consensus among the scientific community is that, despite recent increases documented by the aerial survey, seagrass coverage is considerably less than in the early 1900s. A disease virtually eliminated eelgrass (*Zostera marinus*) from the Coastal Bays in the 1930's, leading to drastic declines in the acreage covered by seagrasses in general. The 2002 acreage represents the second highest total documented in the Coastal Bays, a 320 % increase since annual data began to be collected in 1986. Even though the 2002 numbers show a decrease, seagrass acreage in Maryland's Coastal Bays has increased steadily since annual monitoring began, declining only four times in the 18 year history of the survey. Although seagrasses are found in four major segments of Maryland's Coastal Bays, they are not distributed evenly. Almost 85 percent of all seagrasses occur along the Assateague Island shoreline in Sinepuxent and Chincoteague Bays.

Introduction

Seagrasses have been monitored annually since 1986 through aerial surveys conducted by the Virginia Institute of Marine Sciences (VIMS) and funded by the States of Maryland and Virginia, and the federal government. Despite recent increases documented by the aerial survey, general consensus among the scientific community is that current seagrass levels are considerably lower than the potential available habitat may allow. In the early 1930's, 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.

Although the historic losses of seagrass are largely attributable to disease rather than water quality changes, water quality conditions play a critical role in seagrass distribution. Light limitation will ultimately determine the extent of Coastal Bay seagrass populations. In the Chesapeake Bay, water quality goals have been established based on depth of light penetration (as an indicator of potential habitat availability). In areas where water quality is suitable for seagrass growth, other factors that may limit seagrass distribution in the Coastal Bays include substrate suitability, percent organic content of the sediment (eelgrass prefers sediment with an organic content <5%; however, widgeon grass has a greater ability to grow on soft, muddy substrates (Hurley 1990)) and exposure (how shallow seagrass can grow is limited by wave energy).

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

Summary of Seagrass Indicators

Abundance Indicator:	Seagrass acreage
Draft coverage Indicator:	percent bottom area covered.
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 Habitat Index indicator:	Index = 1.0

A. Seagrass Abundance

The abundance and distribution of seagrasses are an important part of the Coastal Bays ecosystem. Seagrasses are used as nursery for many species. Not only do seagrasses improve water quality, 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).

Abundance Data Sets

Seagrasses have been monitored annually in the Coastal Bays by VIMS since 1986 using aerial photography (Orth et al. 2003).

Indicator: Seagrass abundance (acreage)

Abundance Analyses

VIMS digitization of aerial photos (Orth et al. 2003); DNR categorization into bay segment.

Status and Trends of Seagrass Abundance

Total seagrass coverage in the Coastal Bays following the 2002 survey is shown in Figure 6.1.1. Overall, 17,885 acres (10,511 in Maryland) of seagrass were mapped, a nine percent decrease from 2001. Descriptions of abundance in each individual bay segment follow as well as estimates of the amount of bottom area covered by seagrasses.

Assawoman Bay

In 2002, there were 406 acres of seagrass in Assawoman Bay representing an 8% coverage of bay bottom (Figure 6.1.2). Seagrass coverage has increased an average of 43 acres per year since it first appeared in 1991.

St. Martin River

In 2002, there were 2 acres of seagrass in St. Martin River representing a <1% coverage of the bay bottom (Figure 6.1.3). SAV first appeared in St. Martin River along the Isle of Wight Management area in 1999.

Isle of Wight

In 2002, there were 234 acres of seagrass in Isle of Wight Bay representing a 5% coverage of the bay bottom (Figure 6.1.4). Seagrass coverage has increased an average of 21 acres per year since it first appeared in 1992.

Sinepuxent

In 2002, there were 2135 acres of seagrass in Sinepuxent Bay representing a 36% coverage of the bay bottom (Figure 6.1.5). Seagrass coverage has increased an average of 126 acres per year since 1986.

Newport

In 2002, there were 113 acres of seagrass in Newport Bay, which represents 3.5% of bay bottom covered (Figure 6.1.6). Seagrass coverage has increased an average of 7 acres per year since 1990 when it first appeared in Newport Bay along the lower eastern shore of the bay. Large increases have occurred during two distinct periods: first from 1996 to1997 when acreage jumped from an average of 20 acres to 75 acres and between 2000 - 2001 when acreage jumped from an average of 60 acres to 120 acres.

Chincoteague Bay

In 2002, there were 14,995 acres of seagrass in Chincoteague Bay representing a 32% coverage of the bay bottom (Figure 6.1.7). Seagrass coverage has increased an average of 753 acres per year since 1986 when monitoring began.

Seagrass Abundance Summary

Seagrasses are an important indicator of bay health. The largest distribution of seagrass in the Coastal Bays occurs in Chincoteague Bay (14,995 acres) while the largest percent bottom area covered by seagrasses occurs in Sinepuxent Bay (36%) (Figure 6.1.1). Distribution of seagrasses in the northern bays is limited, presumably due to poorer water quality conditions (see Section 4 of this report).

Results for 2002 show that seagrass acreage decreased 6 percent from 2001 to 2002 to approximately 18,087 acres (10,511 acres in Maryland) (Figure 6.1.1). Yet, the 2002 acreage represents the second highest abundance documented by the monitoring program and a 320 percent increase since the survey began in 1986 (Figure 6.1.1). Even though the 2002 numbers show a slight decrease, seagrass acreage in Maryland's Coastal Bays has exhibited a steady increase since annual monitoring began, and has only declined four times in the 16 year history of the survey.

Density is not an MCBP indicator and is therefore not addressed in this report.

An evaluation of percent available habitat being met would be a better indicator of the status of seagrass in the bays than percent bottom area covered. USACE (1998) estimated that 30,000 acres of potential habitat to 1 m depth existed in the coastal bays, however this estimate did not include consideration of substrate type. Bathymetric data used in USACE (1998) was National Ocean Service chart, much better data is now available. Other factors that might be useful to evaluate potential seagrass habitat include sediment type (percent organic composition), depth, historic distribution and wave energy.

B. Seagrass Habitat Criteria

Although seagrasses are found in all four major segments of Maryland's Coastal Bays, they are not distributed evenly. Almost 85 percent of all seagrasses occur along the Assateague Island shoreline. In the northern bays, seagrass abundance is limited presumably due to reduced water quality from human activities.

Increased nutrient inputs from point and non-point sources and sediments in the water column decrease the amount of sunlight reaching seagrasses and are considered the primary threat to seagrass 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.

Seagrasses are widespread, ecologically important and sensitive to some environmental variables that are measured in many standard water quality monitoring programs (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 seagrass meadows.

Seagrass Habitat Data Sets

Monthly data from 41 Maryland Department of Natural Resources and 18 National Park Service water quality stations was compiled for a three-year time period (2001-2003). Neither data set included data beyond October 2003. 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).

***Draft* Habitat Indicator 1:**	Chl *a* < 15 µg/l
***Draft* Habitat Indicator 2:**	DIN < 0.15 mg/l
***Draft* Habitat Indicator 3:**	DIP < 0.02 mg/l
***Draft* Habitat Indicator 4:**	TSS < 15 mg/l
***Draft* Habitat Indicator 5:**	Secchi >0.966 m or on bottom (>40% of time)

Seagrass Habitat 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 thru May and October thru November) and *Ruppia maritima* (April thru October). Median values for each indicator (except Secchi depth; see below) at each station were evaluated against accepted 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, studies by Valdez (1998) and Lea et al (2003) suggest that the nutrient thresholds are similar in the Coastal Bays, however, the TSS and secchi indicator thresholds may differ between the two systems.

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," suggesting conditions were worse than in reality. For the current analyses, bottom measurements "on bottom" were determined to always indicate adequate seagrass light penetration. Therefore, a percentage of samples that exceeded the Secchi threshold over the three-year period was adopted as a threshold. Samples designated as "on bottom" were always included as meeting the threshold.

Attainment of habitat criteria (except Secchi depth) was tested using a non-parametric Wilcoxon test for position, which compared the three-year medians against the individual criteria. This test determined if water quality conditions at an individual site was significantly different from the criteria being used. The Wilcoxon test was more sensitive to the consistency of the differences (positive or negative) than to their magnitude (Batiuk *et al.* 2000).

Results were classified into four groups (listed below) using a two-tailed significance level of 0.05. The results of the statistical analyses are summarized in Table 6.1.1.

Met – Median was significantly below the criterion

Borderline Met – Median below criterion but not significantly different from the criterion

Borderline Not Met – Median above criterion but not significantly different from criterion

Not Met – Median was significantly above the criterion

Status of Seagrass Habitat Criteria

Assawoman Bay

In Assawoman Bay, the open bay station nearest existing seagrass beds (XDN4851) met all but one habitat criteria while most of the remaining Assawoman Bay stations were either poor or degraded in relation to seagrass habitat thresholds (Table 6.1.1).

St. Martin River

The St. Martin River showed most sites failed seagrass habitat thresholds or water quality variables (Table 6.1.1). Three sites were very degraded, four sites degraded, five poor and only one good with regard to seagrass habitat criteria. This agreed with observations that there was very minimal seagrass growing within this segment.

Isle of Wight Bay

In Isle of Wight Bay there were poorer conditions in the tributaries with little seagrass and fewer habitat criteria being met in Herring and Turville Creeks. Better conditions existed in the open bay with evident seagrass beds and a higher proportion of met habitat criteria along the eastern shore, despite the presence of heavy urbanization (Table 6.1.1). Here, as in Chincoteague Bay, sediment and physical characteristics may play a role with silty sediments dominating Turville and Herring creeks in the west and sandier sediments more prevalent along the eastern portion of the bay (Wells et al. 1994).

Sinepuxent Bay

All stations in Sinepuxent Bay met all criteria except one (TSS at ASIS 17 did not meet the criteria, but was not significantly different from the criteria either) (Table 6.1.1). Noticeably absent were seagrass beds around the two stations nearest the Ocean City inlet (ASIS 1 and ASIS 17), despite meeting most of the habitat criteria. The strong currents coming from the inlet probably make this area unsuitable for seagrass growth and may also contribute to the elevated TSS levels at site ASIS 17.

Sinepuxent stations also have some of the highest percentage values for Secchi criteria attainment among the stations. This could be a result of the shallow water depth in Sinepuxent Bay when compared to the other bays, and the flushing with "clear" ocean water but this remains an interesting characteristic when determining seagrass habitat suitability.

Newport Bay

Stations in the upper tributaries of Newport Bay did not meet or were categorized as borderline for more than one criteria (Table 6.1.1). Attainment of Secchi depth criteria tended to be lower in these upstream waters as well. The two stations in the Bay proper either met or were borderline for most thresholds. As expected, the station nearest the existing seagrass beds along the western edge of South Point (ASIS 3) had the most thresholds met and a relatively high Secchi depth percentage. However, this station was still a fair distance from existing seagrass beds.

Chincoteague Bay

Generally, stations with a majority of criteria met were in close proximity to existing seagrass beds (see previous section on seagrass abundance). However, several stations not near seagrass beds also demonstrated generally good conditions for seagrass growth (Table 6.1.1). For instance, Assateague Island stations 7, 14, 9, and 10 along the western shore of Chincoteague Bay generally met most criteria for water quality and had relatively high percentages of Secchi depth meeting or exceeding the criteria. There is little seagrass growing near these stations (Table 6.1.1).

Seagrass Habitat Criteria Summary

Although stations along the western shore of Chincoteague Bay generally met most criteria for water quality and had relatively high percentages of Secchi depth meeting or exceeding the criteria, there were few seagrass beds present. Several explanations for this are possible. First, the small amounts of seagrass growing along the western shore of Chincoteague could be poised to expand due to improved habitat conditions. However, indicators of water quality (see Chapter 4.1) suggest no trend prior to the three-year period used for this analysis. Another possible explanation could be that since this eelgrass habitat analysis only includes water quality and clarity indicators, physical habitat characteristics conducive to seagrass growth, such as sediment characteristics or hydrology were not considered. Sediment type as well as other factors can play roles in the presence of seagrass. For instance, some types of seagrass (eelgrass specifically) are documented to have less success growing in silty, organic-rich sediments (Batiuk et al. 2000). The sediment of the western shore of Chincoteague Bay tends to have a higher proportion of silt than the sandy eastern portions of the bay (Wells et al. 1998). In addition, there is a high input of organic matter from eroding marsh peats in some areas.

Sediment and physical characteristics may also play a role in seagrass distribution in the St. Martin River and Isle of Wight Bay. Silty sediments dominate the St. Martin River, Turville and Herring creeks in the west and sandier sediments predominate along the eastern portion of the bay (Wells et al. 1994). In Assawoman Bay, the station nearest existing seagrass beds (XDN4851) meets all habitat criteria but all the stations remaining do not meet at least one and are not near seagrass beds.

The low proportions of Secchi depth percentages meeting the threshold across all stations regardless of seagrass presence serves as a warning that criteria developed for the Chesapeake Bay may not suffice. Secchi depth data were 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 seagrass growth and were grouped as passing the criterion. Secchi depth results were reported simply as the percentage of measurements over the three-year period that passed the criterion. Additionally, coefficients to convert secchi depth to light attenuation (K_d) were thought to be variable in the Coastal Bays based on the dominant sediment material resuspended in the water column.

We recommend measuring photosynthetically active radiation (PAR) directly at all stations using a simultaneous, two depth setup in order to calculate percent light in water directly. A three year study by Lea *et al* (2003) suggests that the K_d habitat criteria in the Coastal Bays (1.38) is less than that in the Chesapeake Bay (1.50) and is potentially limiting seagrass growth in some areas of the Coastal Bays.

Bay Segment	Station	SECCHI	TSS	CHLA	DIP	DIN
Assawoman Bay	XDN4851	28%	░			
	XDN5737	24%	░	▓		
	XDN6454	24%	░	▓		
	XDN7261	29%	░	▓		
	XDN7545	28%		█		
	GET0005	#####				█
St. Martin River	BIH0009	#####			░	█
	BNT0012	#####			█	█
	BSH0008	16%	▓	█		█
	BSH0030	0		░	█	█
	MXE0011	#####	░		█	█
	SPR0002	12%	▓	█		░
	SPR0009	8%	▓			▓
	XDM4486	12%	▓	█		█
	XDN3724	36%	▓	▓		
	XDN4312	27%	▓	▓		
	XDN4797	15%	▓	█		▓
Isle of Wight Bay	HEC0012	23%	▓	░		
	MKL0010	42%		░		
	TUV0011	31%	░	░		
	TUV0019	58%	▓	▓		▓
	TUV0034	#####			█	█
	XDN0146	46%	▓			
	XDN2340	27%	░			
	XDN2438	42%	░			
	XDN3445	31%	░			
Sinepuxent Bay	ASIS 1	44%	░		░	
	ASIS 2	56%	░		░	
	ASIS 16	44%	░			
	ASIS 17	48%	▓			
	ASIS 18	52%	░			
Newport Bay	AYR0017	4%	█	█		░
	MSL0011	8%	▓	█		▓
	NPC0012	12%	░	▓		█
	NPC0031	15%	▓	▓		█
	TRC0043	8%	█	█	█	░
	TRC0059	53%			█	█
	XCM4878	24%	░	▓		
	ASIS 3	22%	░	░		
	ASIS 4	30%	▓	░		

Bay Segment	Station	SECCHI	TSS	CHLA	DIP	DIN
Chincoteague Bay	XBM1301	36%	░		▓	
	XBM3418	40%	░			
	XBM5932	28%	░			
	XBM8149	28%	▓			
	XCM0159	28%	▓			
	XCM1562	36%	░			
	ASIS 5	37 %	░			
	ASIS 6	41 %				
	ASIS 7	37 %	▓		░	
	ASIS 8	59 %			█	
	ASIS 9	44 %	▓		░	
	ASIS 10	48%	░		░	
	ASIS 11	67%	▓		▓	
	ASIS 12	70%	▓		▓	
	ASIS 13	70 %			▓	
	ASIS 14	37 %	▓		░	
	ASIS 15	41 %				

Met	Borderline Met	Borderline Not Met	Not Met	Insufficient Data
	░	▓	█	#####

Table 6.1.1: Coastal Bays seagrass habitat criteria test results for all current Coastal Bays stations 2001-2003. The Secchi depth test is the percentage of samples (station per month per year) passing at the 0.966 m criterion with samples that were "on bottom" automatically passing. For all other indicators, statistical results are summarized by station using the color-shaded chart.

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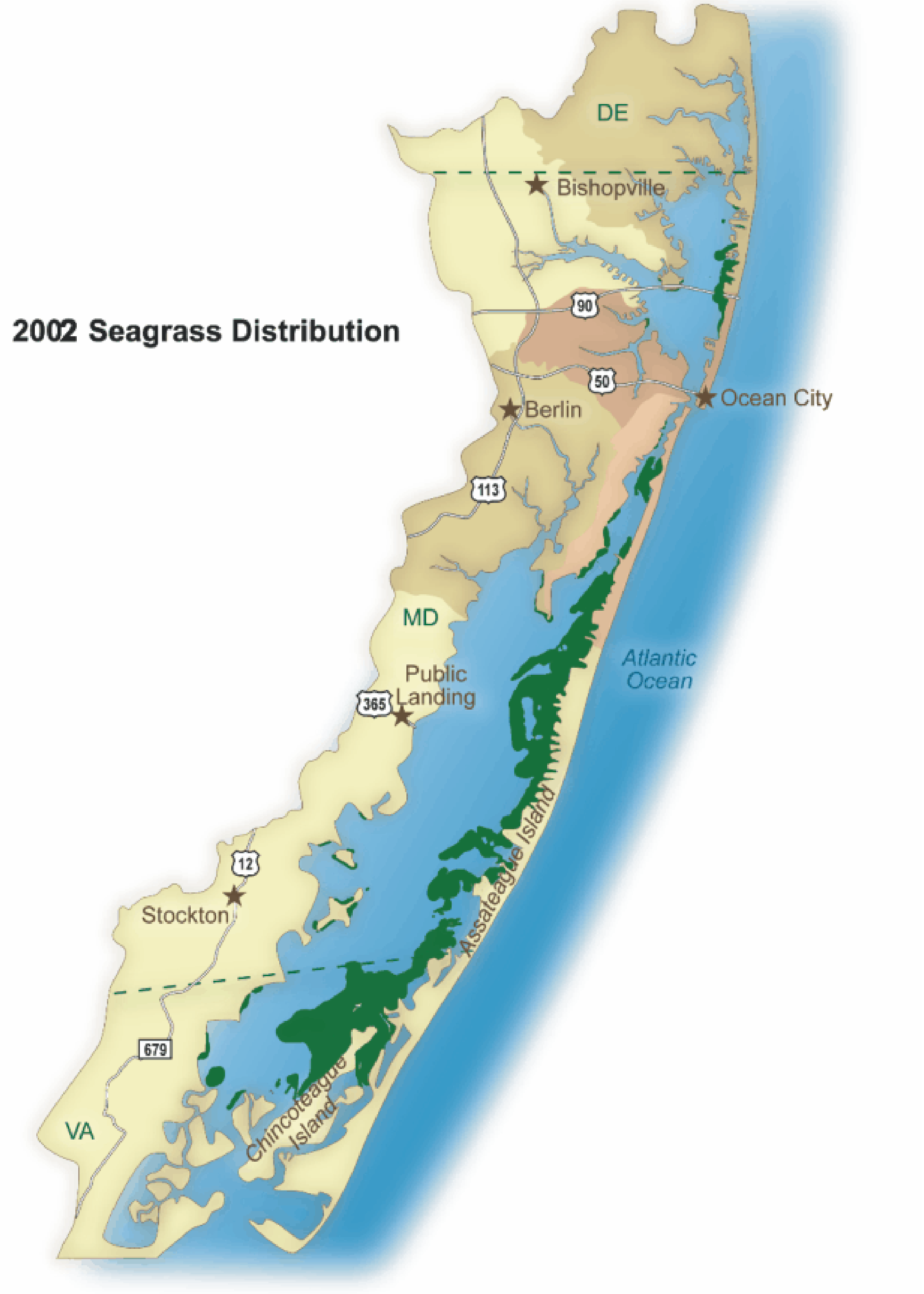

Figure 6.1.1: Total seagrass coverage in the Coastal Bays as discerned from 2002 Virginia Institute of Marine Science aerial survey.

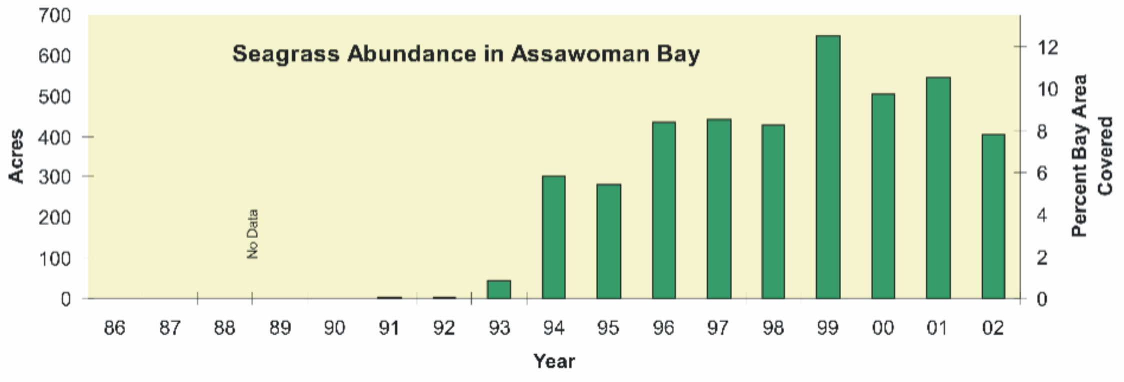

Figure 6.1.2: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in Assawoman Bay.

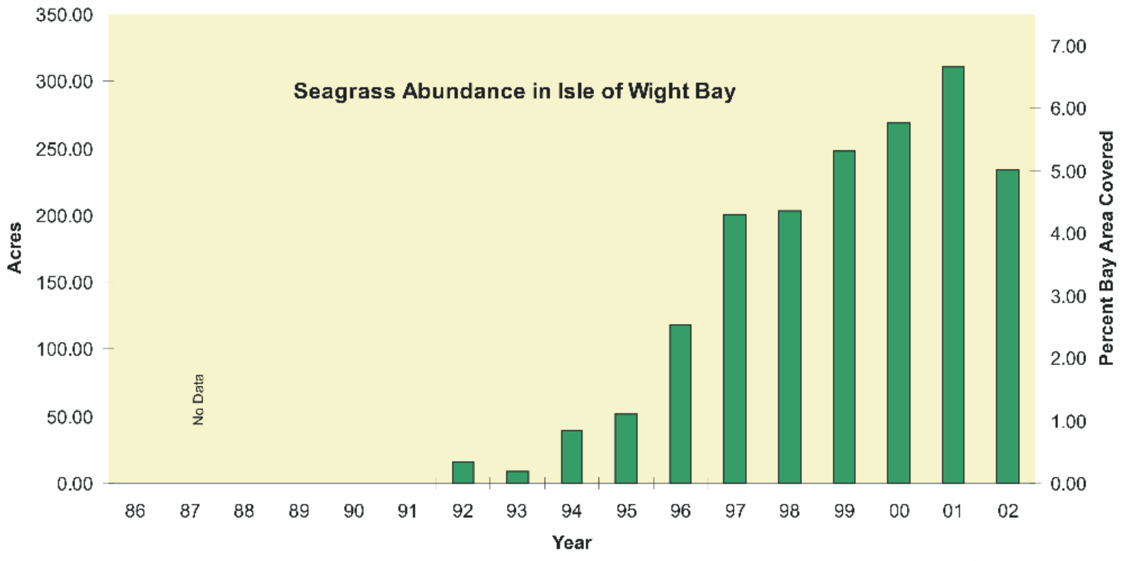

Figure 6.1.3: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in Isle of Wight Bay.

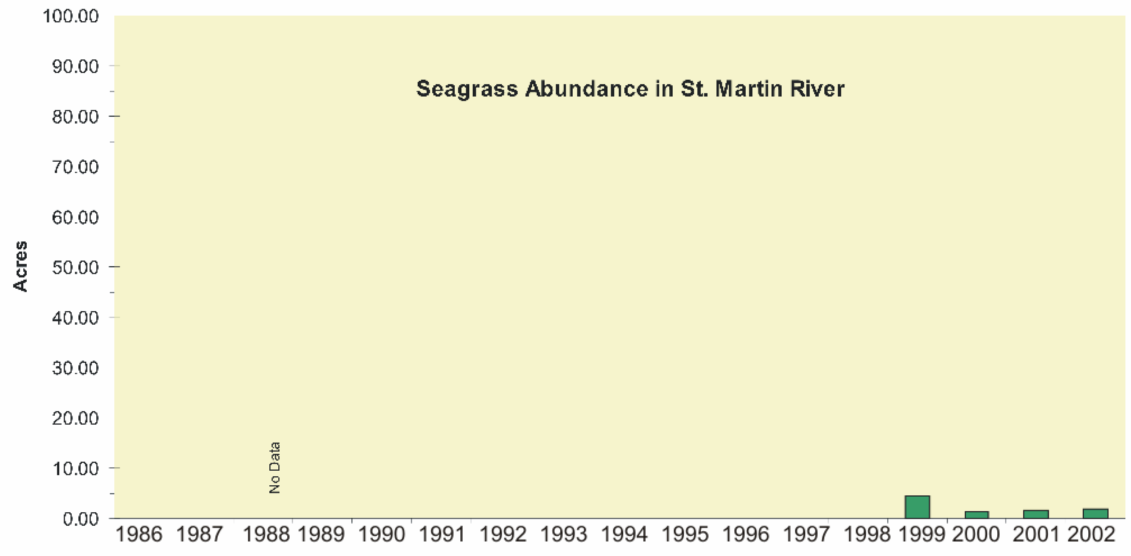

Figure 6.1.4: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in the St. Martin River.

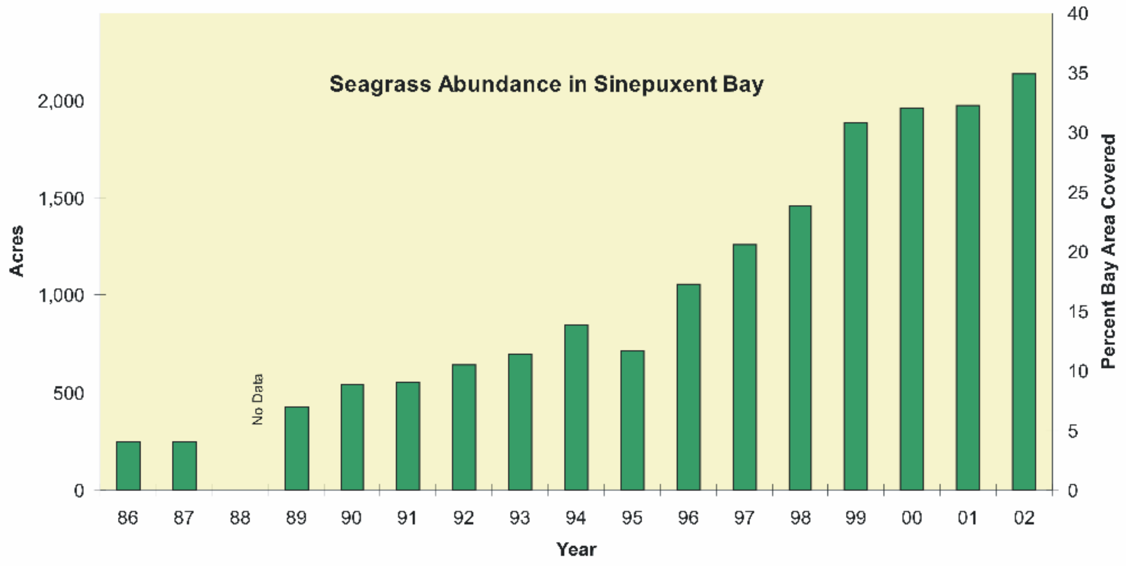

Figure 6.1.5: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in Sinepuxent Bay.

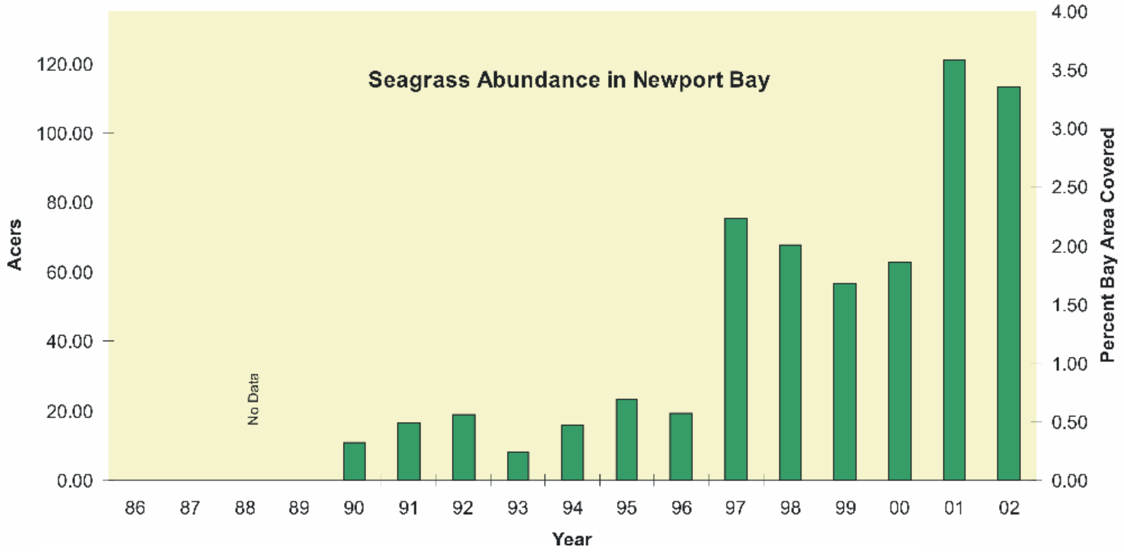

Figure 6.1.6: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in Newport Bay.

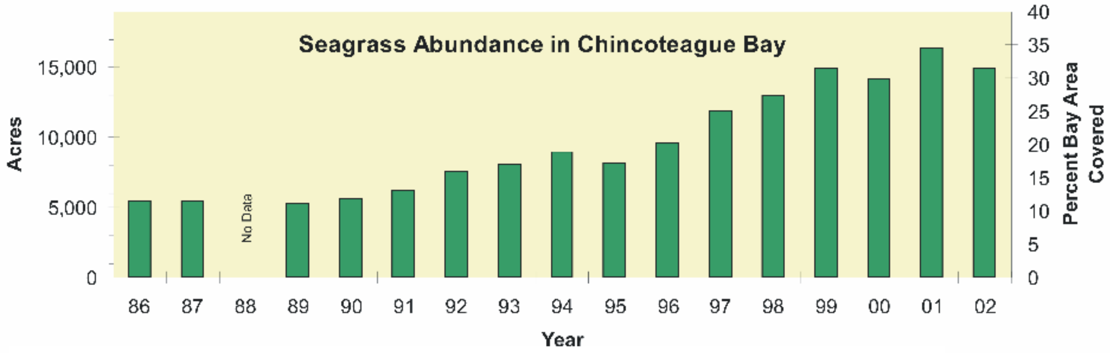

Figure 6.1.7: Annual seagrass acreage (left y-axis) and percent bottom area covered (right y-axis) in Chincoteague Bay.

Chapter 6.2

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

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Abstract

The SAV Index by region appears to be less representative than the water quality index. Although both used "seagrass habitat criteria, " there was a significant difference between seagrass habitat criteria achievement for total nutrients vs. dissolved nutrients. Future evaluation of habitat criteria should include total nutrients, since more stations met the inorganic nutrient criteria (Table 6.2.3), but demonstrated relatively poor status when analyzed for total nutrients

Introduction

A seagrass habitat suitability index 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.

Data Sets

Same data sets used in Chapter 6.1.

Indicator: Submerged Aquatic Vegetation Index (SAVI) = 1.0 (100% attainment)

Data Analysis

To summarize seagrass (SAV) habitat criteria attainment, standard water quality indicators measured from 2001 through 2003 were compiled into a Submersed Aquatic Vegetation suitability Index (SAVI). The index was calculated for each station (Figure 6.2.1) and also for each bay segment (Table 6.2.2). This index was based on compliance of measured water quality indicators (Chlorophyll *a*, dissolved inorganic nitrogen, dissolved inorganic phosphorus, total suspended solids, and Secchi depth) to established habitat criteria for survival of seagrasses (Table 6.2.1). Index values range from zero (no habitat criteria for seagrass survival attained) to one (all habitat criteria for SAV survival met). This approach of summarizing compliance of water quality indicators with habitat criteria 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 6.2.1: Indicators and habitat criteria values used in the calculation of an SAV index for Maryland Coastal Bays (1: Dennison *et al*, 1993; 2: Stevenson *et al*, 1993, 3: Chapter 6.1 of this report).

Indicator	Habitat criteria 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, 3

For each station with greater than ten records for each indicator, medians were calculated for each indicator. 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 indicator were compared to habitat criteria values and scored as one (meets criteria) or zero (fails to meet criteria). These scores were summed for all indicators and divided by the number of indicators 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 presented by measured indicator and index values in Tables 6.2.2 and 6.2.3. 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

Sinepuxent Bay showed the best habitat health with Chincoteague Bay, followed by Isle of Wight Bay and Assawoman Bay respectively (Table 6.2.2). Assawoman Bay failed Secchi and chlorophyll parameters while Chincoteague Bay more often failed due to Secchi and TSS parameters (Table 6.2.3).

Table 6.2.2: SAV suitability Index by reporting region calculated from median values (March – November; 2001-2003)

Region	n (sites)	SAVI	Health
Assawoman	6	**0.63**$_{(0.06)}$	Good
St Martin	11	**0.41**$_{(0.05)}$	Poor
Isle of Wight	9	**0.77**$_{(0.06)}$	Good
Sinepuxent	5	**1.00**$_{(0.00)}$	Excellent
Newport	12	**0.48**$_{(0.05)}$	Poor
Nth Chincoteague	6	**0.77**$_{(0.06)}$	Good
Sth Chincoteague	11	**0.80**$_{(0.05)}$	Good

Table 6.2.3: SAV suitability Index scores, by measured indicator, based on median values (March – November; 2001-2003). Standard error is presented in parentheses.

	Secchi	TSS	CHL	DIP	DIN
Assawoman	0.00 (0.00)	0.83 (0.17)	0.33 (0.21)	1.00 (0.00)	0.83 (0.17)
StMartin	0.00 (0.00)	0.45 (0.16)	0.36 (0.15)	0.73 (0.14)	0.36 (0.15)
Isle of Wight	0.50 (0.19)	0.67 (0.17)	0.89 (0.11)	0.89 (0.11)	0.89 (0.11)
Sinepuxent	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Newport	0.11 (0.11)	0.67 (0.14)	0.50 (0.15)	0.58 (0.15)	0.42 (0.15)
North Chincoteague	0.17 (0.17)	0.67 (0.21)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
South Chincoteague	0.73 (0.14)	0.64 (0.15)	1.00 (0.00)	0.64 (0.15)	1.00 (0.00)

Summary

The SAV Index by region appears to be less representative than the WQ Index (Figures 6.2.1 and 4.4.2). Although both used "seagrass habitat criteria, " there was a significant difference between seagrass habitat criteria achievement for total nutrients (see Chapter 4.4, specifically Table 4.4.2) and dissolved nutrients (Table 6.2.3). Future evaluation of habitat criteria should include total nutrients, since more stations met the inorganic nutrient criteria (Table 6.2.3), but demonstrated relatively poor status when analyzed for total nutrients (see Chapter 4.1, specifically Figures 4.1.1 and 4.1.2).

Since data on light availability were flawed (due to many secchi reading of 'on bottom'), this parameter was not weighted heavier than the other indicators. However, as a general first iteration of SAV habitat testing, these results tend to follow the spatial pattern of SAV distribution (see Chapter 6.1 of this report).

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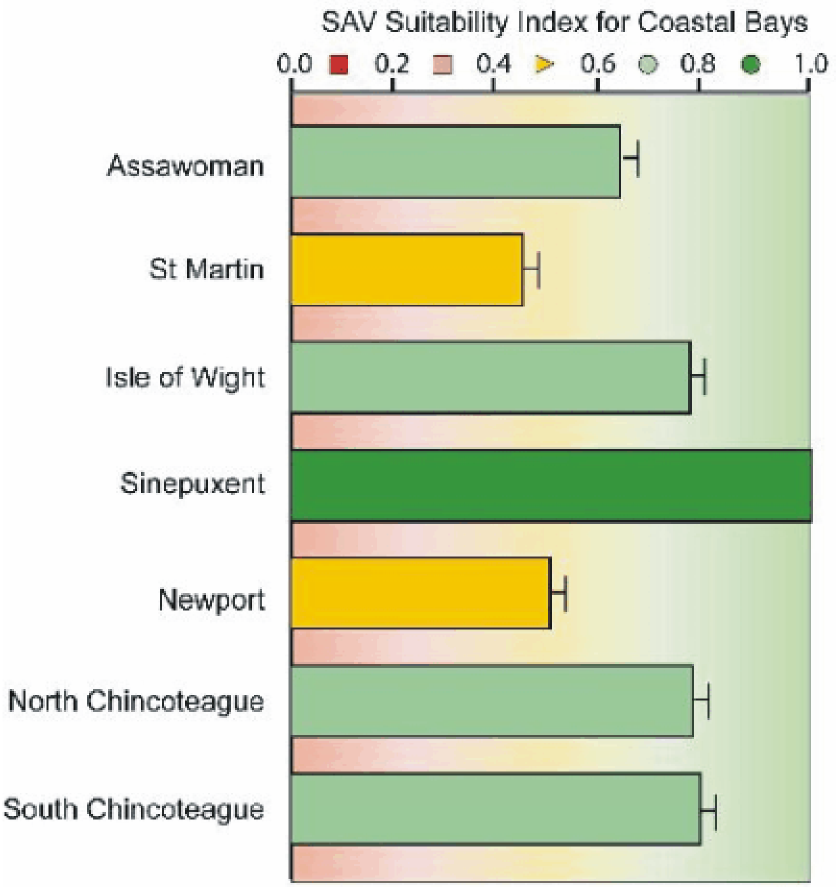

Figure 6.2.1: Seagrass index (SAVI) results for each Coastal Bays segment.

Chapter 6.3

Results of recent macroalgae surveys in the Maryland Coastal Bays

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Abstract

Macroalgae, also known as seaweeds, are abundant and well distributed in the Coastal Bays. Estuarine ecosystems with generally well-illuminated shallow bottoms and moderate to high nutrient loadings can be optimal environments for the development of high concentrations of macroalgae. Macroalgae (seaweeds) are large plant-like structures found in coastal waters worldwide. Three main types, divided by coloration, are present along the Atlantic coast – green, red, and brown. Experts believe that a shift in the dominant primary producers, from slower growing sea grasses to faster growing phytoplankton, is indicative of eutrophication (i.e., excessive nutrient concentration) in a system. The presence of macroalgae blooms may be a sign of a system's progression toward a degraded state. Macroalgal distribution and biomass were investigated in tidal locations throughout the Coastal Bays during the winter, spring, summer, and fall seasons. Eighteen genera of macroalgae were identified in Maryland's Coastal bays including six green macroalgae, eight red macroalgae, and four brown macroalgae. There was no statistical difference in the abundance of macroalgae among seasons; however, there were distinct seasonal shifts in which genera were dominant. The amount of macroalgae averaged 4.3 grams per liter (g/L) for all samples, with peak biomasses of 316.1 g/L in Turville Creek and 443.5 g/L in Chincoteague Bay. Nutrient responsive species were accountable for 39% of the overall biomass and were dominant in the northern coastal bays and sea grass beds in Chincoteague Bay. Biomass estimates revealed that the relative dominance of primary producers in each bay segment shifted from sea grass to phytoplankton with increasing nutrient loads.

Introduction

Macroalgae appear in a variety of colors and forms. They are divided into three groupings: red, brown and green -based on pigments (e.g. color of the plant). Benthic macroalgae are recognized as important primary producers in shallow aquatic ecosystems (Duarte 1995 and Valiela et al., 1997). Estuarine ecosystems with generally well-illuminated shallow bottoms and moderate to high nutrient loadings, can be optimal environments for the development of high concentrations of benthic macroalgae. Experts believe that a shift in the dominant primary producers, from slower growing vascular macrophytes to faster growing one-celled phytoplankton, is indicative of eutrophication in a system (Duarte 1995; Valiela et al.1997). The presence of macroalgae blooms may be indicative of a systems progression toward the final eutrophied state.

Macroalgae can appear as small "fur like clumps," moderate-sized branched specimens, or large leaf-type structures. An excess of macroalgae can be problematic for aquatic life (organisms can be impaired or killed as a result of decreased oxygen levels when algae die and decompose), boaters (prop fouling), citizens and tourists (odor). Such excessive levels are categorized as Harmful Algae Blooms. This can particularly be a problem in dead end canals where high nutrient loads and limited flushing make ideal environments for some macroalgae species. Macroalgae are listed as a "nuisance species" in the CCMP (FW 5.2).

Macroalgae monitoring by DNR and ASIS in 199819/99, 2001/2002 and 2003. Distribution of genera and relative abundance information was recorded. Benthic macroalgae distribution and biomass were investigated at 600 tidal locations throughout the Maryland Coastal Bays.

Management Objective: *None*

Data Analysis

Data were converted to biomass by applying unpublished coefficients developed by the Virginia Institute of Marine Science (Goshorn et al. 2000; McGinty and Wazniak 2002). Bay segment estimates were estimated by extrapolating point data for each grid cell, then adding grid cells together (Goshorn et al. 2000; McGinty and Wazniak 2002).

Results: Status of macroalgae

Eighteen genera of benthic macroalgae were identified in Maryland's Coastal Bays including 6 chlorophytes (*Ulva*, *Chaetomorpha*, *Enteromorpha*, *Cladophora*, *Bryopsis*, *Codium*), 8 rhodophytes (*Ceramium*, *Agardhiella/Gracilaria*, *Polysiphonia*, *Champia*, *Ceramium*, *Spyridia*, *Hypnea*, *Chondria*), and 4 phaeophytes (*Desmarestia*, *Ectocarpus*, *Stilophora*, *Sphaerotrichia*). No difference in biomass was observed among seasons; however, there were distinct seasonal shifts in which genera were dominant.

Assawoman Bay

Several genera were observed, dominated by *Agardhiella* and *Ectocarpus*

St. Martin River

Biomass was generally low in the river. *Agardhiella* was present and *Cladophora* was reported in the canals.

Isle of Wight Bay

Hot spot for *Agardhieilla* in Turville Creek. Long Term fisheries trawl site had to be moved in 1999 – 2002. Multiple species were observed, dominated by *Agardhiella* and *Ulva*

Sinepuxent Bay

Numerous genera were observed, dominated by *Agardhiella*, *Ectocarpus*, and *Ulva.*

Newport Bay

Little macroalgae was observed, dominated by *Agardhiella* and *Ectocarpus*

Chincoteague Bay

Hot spot for *Chaetomorpha* in 1998 – 2001. Numerous genera were observed, dominant species included *Chaetomorpha*, *Agardhiella*, and *Ectocarpus*

Summary

Benthic macroalgae biomass averaged 4.3 g/L for all (Figure 6.3.1). *Agardhiella* was most consistently found in Turville Creek with a peak biomass of 316.1 g/L (Figure 6.3.2), and *Chaetomorpha* in Chincoteague Bay at 443.5 g/l (Figure 6.3.3). Macroalgae appeared to show an inverse relationship with water column chlorophyll *a* in all segments; however, no other relationship to water quality parameters were noted. Nutrient responsive species were accountable for 39% of the overall biomass and were dominant in the northern Coastal Bays and seagrass beds in Chincoteague Bay. Biomass estimates revealed that the relative dominance of primary producers in each bay segment shifted from seagrass to phytoplankton with increasing nutrient loads.

Distinct seasonal shifts in which genera were dominant makes it difficult to pinpoint a "reference" sampling season.

Acknowledgements

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Lewandowski tested its efficiency in the field. Chris Tanner provided identification training and QA of samples.

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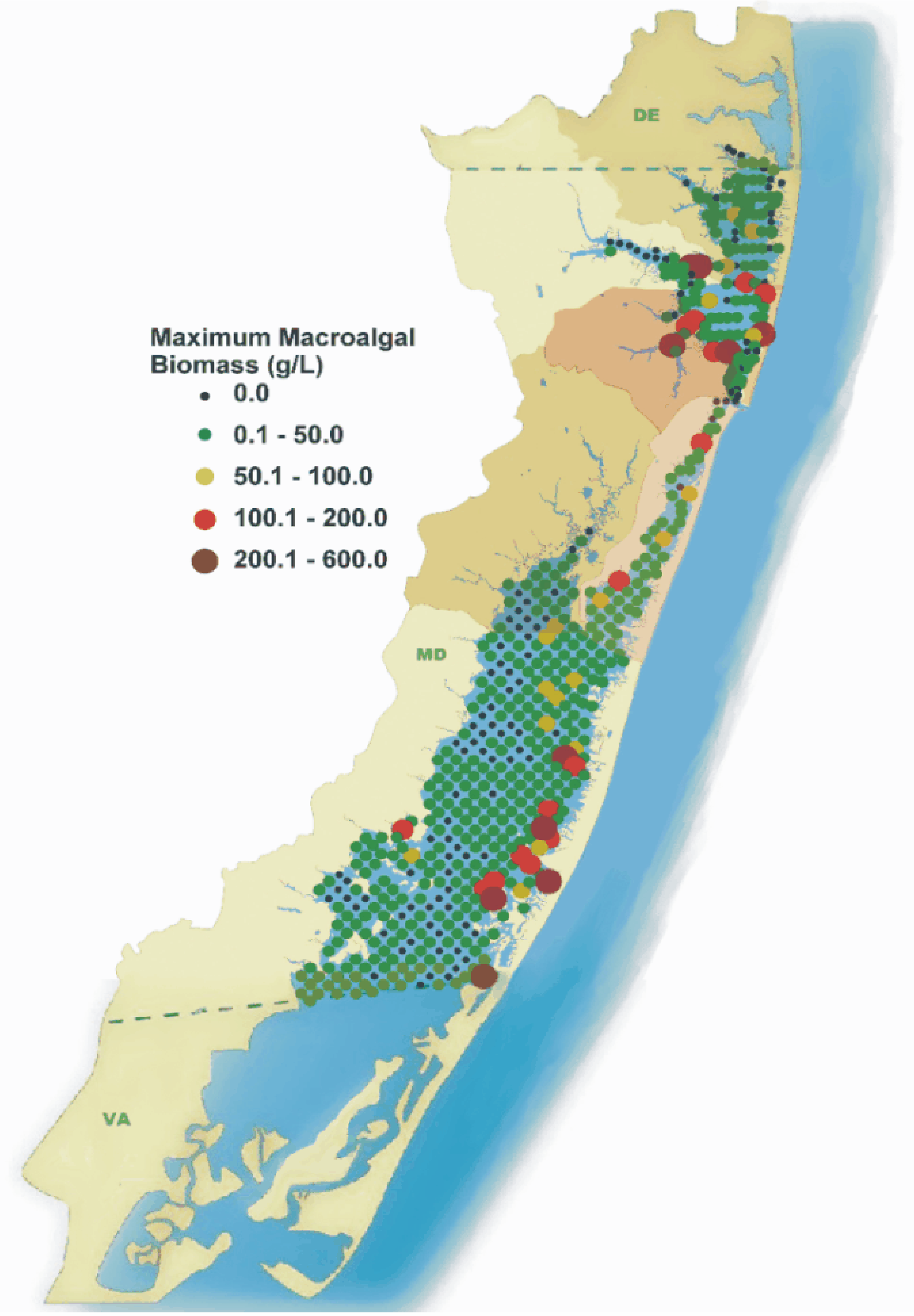

Figure 6.3.1: Maximum total macroalgae biomass per station over all seasons for three survey years (1999/2000, 2001/2002, and 2003). Biomass was converted from sample volume collected on-site (see text).

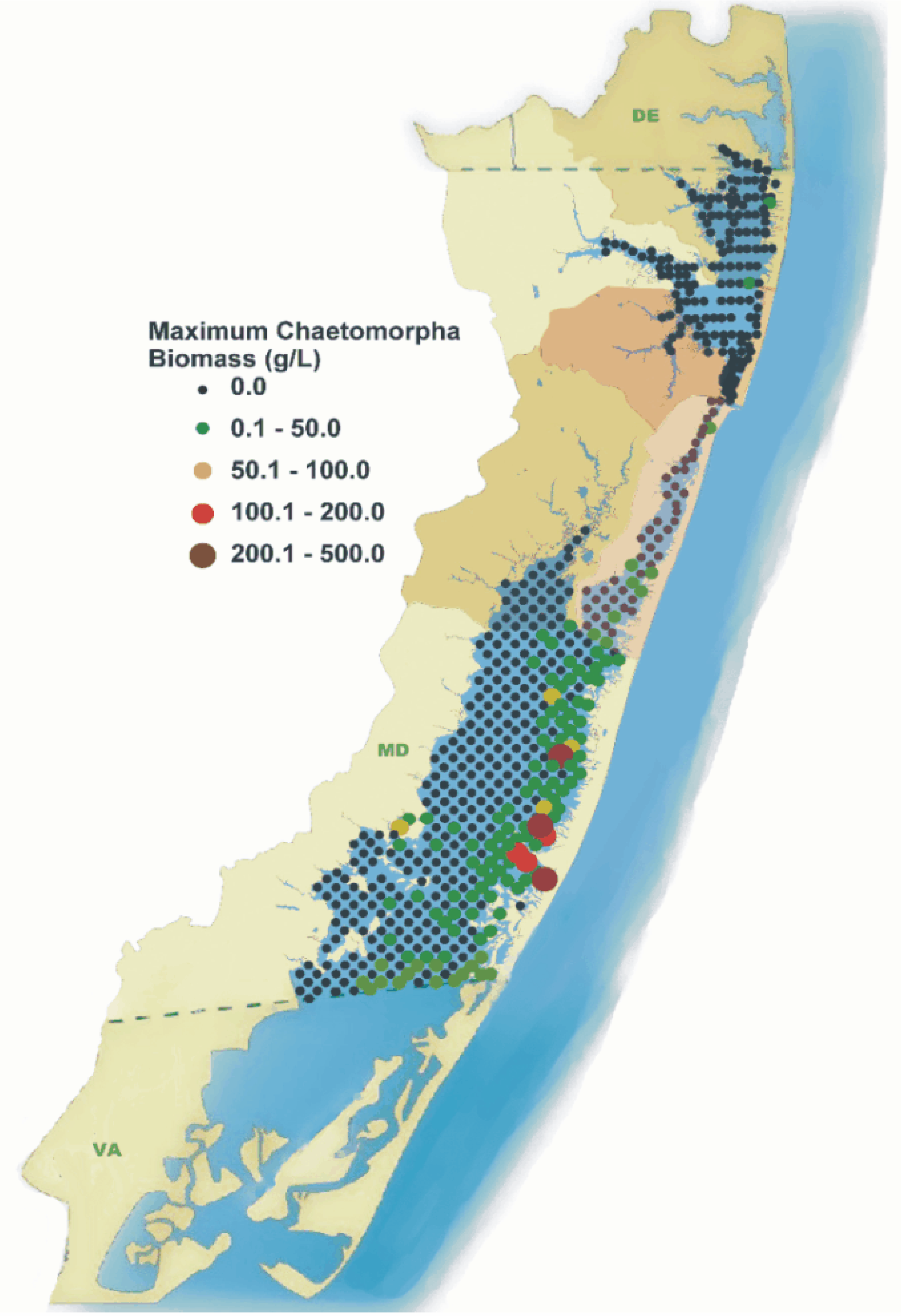

Figure 6.3.2: Maximum total *Chaetomorpha spp*. biomass per station over all seasons for three survey years (1999/2000, 2001/2002, and 2003). Biomass was converted from sample volume collected on-site (see text).

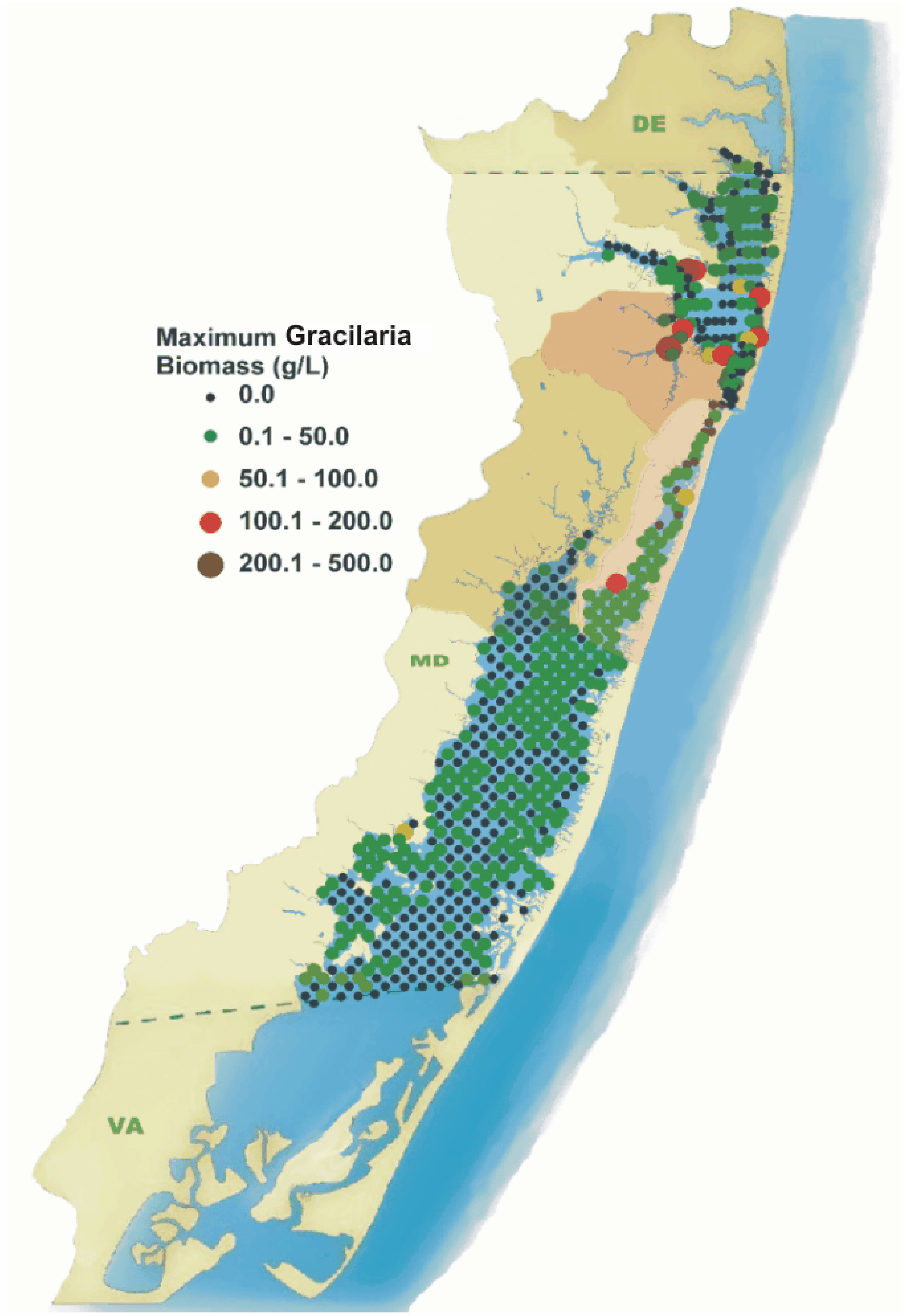

Figure 6.3.3: Maximum total *Gracilaria spp*. biomass per station over all seasons for three survey years (1999/2000, 2001/2002, and 2003). Biomass was converted from sample volume collected on-site (see text).

Chapter 6.4

Status of wetlands in the Maryland Coastal Bays

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Abstract

Current wetland acreageWetlands in the Coastal Bays have decreased substantially, especially in the northern segments. Wetlands drained for agriculture, development, and other human uses decrease habitat for wildlife and adversely affect the land's nutrient and sediment absorbing potential (e.g., buffering capability). Although slowed considerably by federal and state laws restricting impacts to wetlands, losses still occur from human-induced changes in land use, sea level rise and natural processes (erosion). The Coastal Bays watershed has lost an estimated 54,778 acres of wetlands since European settlement. Wetland loss and alteration has occurred from various activities. A network of ditches has drained many tidal and non-tidal wetlands. Tidal wetlands have also been lost due to construction of canals and bulkheads or other hard shoreline stabilization projects. Conversion of wetland to agriculture and development has also resulted in extensive wetland loss. The most recent mitigation guidelines place high weight on restoring wetlands according to needs of the watershed. Attention needs to be paid to the condition of existing wetlands, not just to their supposed existence on a map.

Introduction

There are different estimates of the extent of wetlands in the Coastal Bays, due to differences in accuracy in wetland maps, wetland definitions, and inventories over the past century. Wetland maps still fail to show all wetlands that exist in the watershed, and determinations of wetland extent, connections to other water bodies, or condition are best determined in the field.

Comparing the wetland amount (between surveys) should be done with extreme caution due to differences in methods employed by each survey. Comparisons of wetland acreage based on these surveys should not be used to determine wetland gain/loss for this reason; however, it is reasonable to use this data to characterize general changes/trends. Standard wetland classification scheme based on Cowardin et al. (1979) (excluding deepwater habitats as defined above) is presented below.

Marine wetlands

Marine wetlands encompass ocean area above the continental shelf and the high-energy coastline, including sandy beaches along the Atlantic Ocean. These are most common on Assateague Island and have only sparse amounts of vegetation. These are not directly within the Coastal Bays watershed.

Estuarine wetlands

Estuarine wetlands are tidally influenced and contain salt or brackish water, with amounts of salinity and flooding heavily impacting wetland function. They occur in areas where ocean water is at least partially diluted with freshwater and extend upstream to the zone of freshwater. Subtidal wetlands are permanently inundated with tidal water (see chapter 6.1 for seagrass abundance) while intertidal wetlands alternate between flooded and non-flooded conditions. Estuarine emergent subtidal wetlands occur along the west coast of Fenwick and Assateague Islands. These wetlands have the potential to provide valuable habitat for wildfowl (USACE, 1998). Estuarine intertidal emergent wetlands are common on the mainland shorelines. In the Assawoman Bay Watershed, there are extensive sections of emergent wetland. Other emergent wetlands are in the Isle of Wight Bay Watershed at the wider parts of Turville Creek and Herring Creek, and a few areas in the Northern shorelines of St. Martins River. There are also extensive emergent wetlands along Trappe Creek, at Brockanorton Bay, Martin Bay, Johnson Bay, and on small islands within the Chincoteague Bay. Aquatic beds occur in shallow water areas and often support submerged aquatic vegetation. See chapter 6.1

Palustrine wetlands

Palustrine wetlands are tidal and non-tidal freshwater wetlands located on floodplains associated with streams and rivers, upland depressions, and in flats between drainage systems. The headwaters within the Coastal Bays contain few wetlands, especially in Newport Bay watershed (near Berlin) and Isle of Wight Bay watershed, likely due to historic draining and filling of wetlands for agriculture, upland forest or urban development. In the Coastal Bays, forested wetlands are the most common palustrine type, with many being connected to inland freshwater portions of streams and rivers. Palustrine emergent and shrub wetlands are also present in small amounts.

Table 6.4.1 Estimated Acres of Wetlands in the Coastal Bay watershed. The National Wetland Inventory (NWI) used data collected between 1981-1982. MD Department of Natural Resources (DNR) used data from 1988-1989 and US Fish and Wildlife Service (Tiner et. al. 2000) used data from 1998.

Wetland Classification	GIS data source (acres)		
	NWI	DNR	Tiner et al. 2000
Marine	717.8	369.9	525.2
Estuarine			
Aquatic beds, unconsolidated shore, flat, beaches and bars, unconsolidated bottom	1,086.0	6,404.2	1,085.8
Emergent, scrub-shrub, forested	16,762.5	16,893.1	17,092.8
Palustrine			
Flat, open water, aquatic bed, unconsolidated bottom, unconsolidated shore	369.1	555.3	614.7
Emergent, scrub-shrub, forested	5,488.4	9,989.9	17,109.9
Farmed		443.1	47.2
Total wetlands	**24,424**	**34,730**	**36,805**

NWI data was based on digital ortho quads from 1981-1982 infrared photographs. DNR data was largely based on digital ortho quarter quads from 1988-1989 infrared photographs. Tiner et al. (2000) was based on the DNR GIS wetlands data, 1998 black and white photography, VIMS SAV data, and digitized hydric soils data (Figure 7.4.1). In this document, they acknowledge that forested wetlands may be overestimated due to difficultly in distinguishing between forests that are currently wetlands and ones that were drained but still have hydric soils (Tiner et. al. 2000).

Tidal wetlands in the Coastal Bays were classified in the Coastal Wetlands of Maryland as saline high marsh or saline low marshes (McCormick and Somes 1982). Plant species diversity is typically low, except at the high marsh to the upland border where effects of salinity are diminished (McCormick and Somes 1982). Saline high marshes were dominated by either Meadow cordgrass (*Spartina patens)* and/or Spikegrass *(Distichlis spicata)*, Marshelder/Groundselbush (*Iva frutescens/Baccharis hamifolia*) and Needlerush *(Juncus roemerianus.)* Saline low marshes were dominated by Smooth cordgrass (*Spartina alterniflora*) in its tall or short growth forms. These tidal wetlands have the highest salinities of any tidal wetlands in Maryland. Smaller acreage of tidal freshwater forested wetlands were also found. Acreage distributions based on major wetland type, from 1976-77 field work and photo interpretation from McCormick and Somes (1982), was as follows:

- Saline High Marsh
    - Meadow cordgrass/Spikegrass: 2,304 acres
    - Marshelder/Groundselbush: 1,780 acres
    - Needlerush: 121 acres
- Saline Low Marsh
    - Smooth cordgrass, tall growth form: 95 acres
    - Smooth cordgrass, short growth form: 9,449 acres

There has been some encroachment from *Phragmites australis* in the Coastal Bay tidal wetlands, but it is not extensive (Dawson, pers. comm.).

According to **US Army Corp of Engineers**, there are approximately 16,600 acres of salt marsh along the Coastal Bays, with most being in Chincoteague Bay and about 2,500 acres in the Northern Coastal Bays and 5,300 acres of forest and shrub wetland on the mainland (USACE, 1998). The true wetland amount is probably somewhere between these (various estimates). Spaur et al. (2001) gave consideration to landscape position and used the HGM method for functional assessments.

Based on the **DNR wetland GIS** data, watershed acreage is as follows:
- Assawoman Bay: 2,746 wetland acres (including 20 acres farmed palustrine wetlands).
- Isle of Wight Bay: 5,648 wetland acres (including 193 acres farmed palustrine wetlands) in watershed.
- Newport Bay: 6,546 wetland acres (including 120 acres farmed palustrine wetlands) and 422 meters additional linear wetlands.
- Sinepuxent Bay: 4,023 wetland acres (including 23 acres farmed palustrine wetlands).
- Chincoteague Bay: 15,530 wetland acres (including 87 acres farmed palustrine wetlands) and 6,212 meters additional linear wetlands in watershed."

There are twelve sites designated as nontidal wetlands of special State concern in the Coastal Bays: Hancock Creek Swamp, Little Mill run, Pawpaw Creek, Pikes Creek, Stockton Powerlines, Porter Neck Bog, Powell Creek, Riley Creek and Swamp, Scarboro Creek Woods, Scott's Landing Pond, Tanhouse Creek, and West Ocean City Pond. Wetlands were designated based on presence of rare species and/or being of an unusual or unique natural community.

Data Sets
No real monitoring of wetlands.

Current wetland resources are based on fairly old information (1989 MD. DOQQ and even older NWIs).

The Maryland Department of the Environment keeps records on the extent of wetlands lost or altered through regulatory programs, gains and compensatory mitigation through regulatory programs. Information is also collected on voluntary wetland restoration efforts. A strategy for monitoring wetland condition will be developed within the next several years. Formal functional assessments of wetlands are sometimes conducted for activities proposed for extensive wetland impacts

Management Objectives: No net loss of wetlands
Restoration of 10,000 acres.

Management objectives of various agencies and programs are compiled in "Priority Areas for Wetland Restoration, Preservation, and Mitigation in Maryland's Coastal Bays," 2003 (draft) by the Maryland Department of the Environment. Restoration is listed as a particularly high priority in the Isle of Wight, Assawoman Bay, and Newport Bay because of high wetland losses and water quality concerns. Wetland restoration and siting should also be weighed against other needs, including maintenance of wellhead protection areas, prime farmland, and forests. Enhancement of existing wetlands was also recommended. Creation, restoration and enhancement priorities focus on habitat, water quality improvement, stormwater management, and shoreline stabilization. Specific areas recommended for protection include nontidal wetlands of special State concern.

Wetland Indicator: wetland loss

Data Analyses

Tracking of permitted losses and gains. Estimates of historic losses using two methods: Tiner hydric soils and ACOE Natural Soils GIS data.

Results

Permitted Losses: Little attention was paid to wetlands during the settlement of Maryland. Land which held water or was saturated and soggy during the growing season was regarded as a nuisance or an impediment to agriculture and was altered and drained wherever feasible. In the intervening centuries since settlement the value of wetlands for habitat and for water quality has been studied and increasingly recognized to the point where protection of remaining wetlands and consideration of restoration of altered wetlands is now considered. Lack of record keeping makes it difficult to know exactly how much of the area's wetlands have been altered or where they were prior to settlement. Current regulations require a permit for impacts to wetlands above a size threshold. If a permit to impact a wetland is applied for and granted the area of wetland impacted by the permitted activity is tabulated as permitted loss. Permitted losses are required to be offset by wetland creation elsewhere or by other acceptable mitigation. The difference between permitted losses and mitigation is reported as net loss. Maryland Department of the Environment tracks and reports on net loss (or gain) of wetlands in watershed. Table 7.4.2 shows the permitted wetland gains and losses collected by the Department of the Environment.

Table 6.4.2 Permitted wetlands gains and losses in the Coastal Bays.

	Wetland Gains and Losses in Coastal Bays						
Nontidal Wetlands							
1991-2003							
	Assawoman Bay	Isle of Wight	Sinepuxent Bay	Newport Bay	Chincoteague Bay	Unknown	Total
Permanent Impacts,							
regulatory	-0.71	-67.61	-4.47	-5.62	-2.04		-80.45
Permittee Mitigation		46.85	3.47	3.45			53.77
Programmatic Mitigation							
(MDE)		5	3	0.5	11.4		19.9
Other Gains		1.16	0.09	0.8	3.92		5.97
Net change, regulatory							
program	-0.71	-14.6	2.09	-0.87	13.28		-0.81
Tidal Wetlands	-0.0357	-0.3382	-0.2172	-0.165	0		-0.7561
1996-2003 incl. SAV							
open water, mudflat,							
veg. Wetland							
Tidal wetland 1996-2003							
mitigation		0.4508	0.092				0.5428
Voluntary restoration	92.15	143.3	39.1	213.6	565	823.4	1876.55
1998-*							
****2003,2004 records***							
incomplete							
						3/31/2004	
	Voluntary restoration may be in tidal or nontidal wetlands						

Historic Losses

The technique for estimating the loss of wetlands by type was developed by Ralph Tiner of the U.S. Fish and Wildlife Service, National Wetland Inventory, Hadley MA. Because saturated soils have different chemical processes from aerated soils, they develop distinctive properties which can be identified and mapped. Collectively these soils are known as hydric soils and the hydric signature can be observed even after the land has been drained and disturbed somewhat. Mapping soils classified as hydric which are not within a wetland as determined by the National Wetland Inventory or the Maryland Department of Natural Resources is the usual way of estimating historic wetland loss within a region.

Using this fact, Ralph Tiner examined the soils maps of the Nanticoke River Watershed and produced an estimate of historic loss of wetlands in that watershed. (Tiner et al. 2001). Different hydric soils classifications are associated with different wetland types so it is possible to estimate the type of wetland which occurred there before the wetland was altered. Five separate classes of historic wetland are distinguishable using this method. They are: saturated forest wetland, flooded forest wetlands, flood plain wetlands, depression wetlands and emergent marsh wetlands. In saturated forest wetlands, the Winter and Spring water table is at or just below the soil surface. These areas do not look wet when you are standing in them, but the saturated soils require that the plant roots be adapted to a lack of oxygen in the soil and the presence of precipitated metals. Only plant species able to tolerate these conditions can grow there, so the hydrology drives a plant selection function. Additionally, loblolly pine are one of the commercially important plants which can tolerate these conditions (although they do best in mesic soils). In flooded forest wetlands the water actually ponds above the surface for a substantial portion of the growing season. These wetlands are very important for the maintenance of amphibian populations (frog and salamanders) which need the standing water to complete their life cycle (temporary water bodies in wetlands without regular connection to streams are critical for reproduction). Flooded woods have essentially flat topography and the water accumulates because there is no slope to drain it away. Depression wetlands occupy a low spot in the local topography and collect surface runoff from the surrounding area but have no outlet. The water is evaporated or transpirated by vegetation or eventually recharges the groundwater. Depressions may dry out by the end of the growing season or they may maintain a permanent pool of water. Depressional wetlands can be locations of rare or unusual plant species adapted to long periods of standing water (e.g. DELMARVA Bays). Flood plain wetlands have flowing water associated with them. Flood plain wetlands may receive overland flow from streams during floods and recharge the stream through groundwater base flow during seasonal lower flows. Emergent marshes are fringing wetlands in streams or ponds in the non-tidal areas and are the predominant wetland type in the coastal tidal areas. Emergent marshes are characterized by little or no woody vegetation and a predominance of grass like plants or floating leaved plants. These wetlands are either permanently or episodically flooded.

Wetland loss and alteration has occurred from various activities. Many tidal and nontidal wetlands have been drained by a network of ditches. Tidal wetlands have also been lost due to construction of canals and bulkheads or other hard shoreline stabilization projects.

Conversion of wetland to agriculture and development has also resulted in extensive wetland losses.

Using the soil and land form information, the Coastal Bays have lost 9,845.3 hectares (24,324 acres) of saturated forested wetlands, the largest category of loss. This is to be expected because these are the easiest category of wetlands to drain with ditches. The local water table is lowered to the level of the bottom of the ditch and the soil can then be dried out and tilled. The second highest category of loss is the 7,086.9 hectares (17,512 acres) of flooded forested wetlands. Although larger amounts of water must be removed, it stall can be removed with a ditch.

Losses for flood plain wetlands and emergent wetlands are similar in the extent of impacts, 2,495 hectares (6,165.5 acres) of flood plain wetlands lost and 2,475.6 hectares (6,117.4 acres) of emergent marsh lost since European settlement. These wetlands may be lost due to either dredging or filling. The smallest loss by category are the isolated depressions, 265 hectares (655 acres) of former depressional wetlands can be identified from the soils and landform analysis. These are small wetlands and easy to fill. They may be under counted by this method. Total estimated wetland loss since settlement amounts to 22,168 hectares (54,778 acres).

The Army Corps of Engineers (ACOE Baltimore Dist. Feb. 1998) estimated a loss of Salt marsh (tidal emergent wetlands) of 6,700 hectares which is a larger loss than estimated by the Tiner method. The Corps estimated that 20,700 hectares of nontidal wetlands of all types (mostly forested) have been lost since settlement. This compares with 22,168 hectares lost using the Tiner method. These seem reasonably close for estimates made with two different data sources. The Corps estimates were made using the Natural Soils Groups GIS data prepared in 1990 by the MD Department of Planning. The new estimates done by the Tiner method use the newer NRCS SSURGO GIS data set which has higher resolution soils mapping. The increase in precision of soils mapping is a key to improving the ability to locate lost wetlands and to determine the type of wetland that should be restored at that site.

Historically, restoration has been most successful with the wetter range of wetlands while it is the drier range of wetlands, which have shown the greatest loss. The National Research Council's publication Compensating for Wetland Losses under the Clean Water Act (Natl. Academy Press, 2001) recommends that more attention be focused on recreating wetlands of the type which previously existed rather than focusing on acreage of wetlands restored. This in turn will provide the range of wetland function which previously existed because different classes of wetland provide different mixtures of function to the landscape. However, there have been more recent projects that restore wetlands in the "drier" range in the Coastal Bays watershed. New guidance on mitigation places high weight on restoring wetlands according to needs of the watershed although the resulting wetland composition may differ from historic distribution according to this approach.

In addition to outright loss of wetlands through drainage and conversion to other land use there has been degradation of the biological condition of existing forested wetlands through conversion to Loblolly pine (*Pinus taedeus*) sylvaculture for fiber production. Loblolly pine can grow under wetland condition so there is no need to disturb the hydrology of a wetland. However, forestry practices often create microsite mesic conditions by bedding and drainage practices. Furthermore, the soil and the biota are adversely impacted by the operation of the harvesting and replanting equipment and by the removal of diverse species that may compete with the pine for light and nutrition. Although such forests are still considered a wetland, they do not have the full suite of wetland functions found in an unimpacted forested wetland. Attention needs to be paid to the condition of existing wetlands, not just to their continued existence on a map.

Summary

Attention needs to be paid to the condition of existing wetlands, not just to their continued existence on a map. Wetland areas should be prioritized for restoration and protection.

Current wetland resources are based on fairly old information (1989 MD. DOQQ and even older NWIs). In order to better track the abundance and function of Coastal Bays wetlands need initiate a more comprehensive monitoring program..

There may well be continued losses of tidal marsh from shoreline erosion even with protection of existing wetlands through regulation (these are not currently made up by natural processes due to incompatibility with humanity’s needs).

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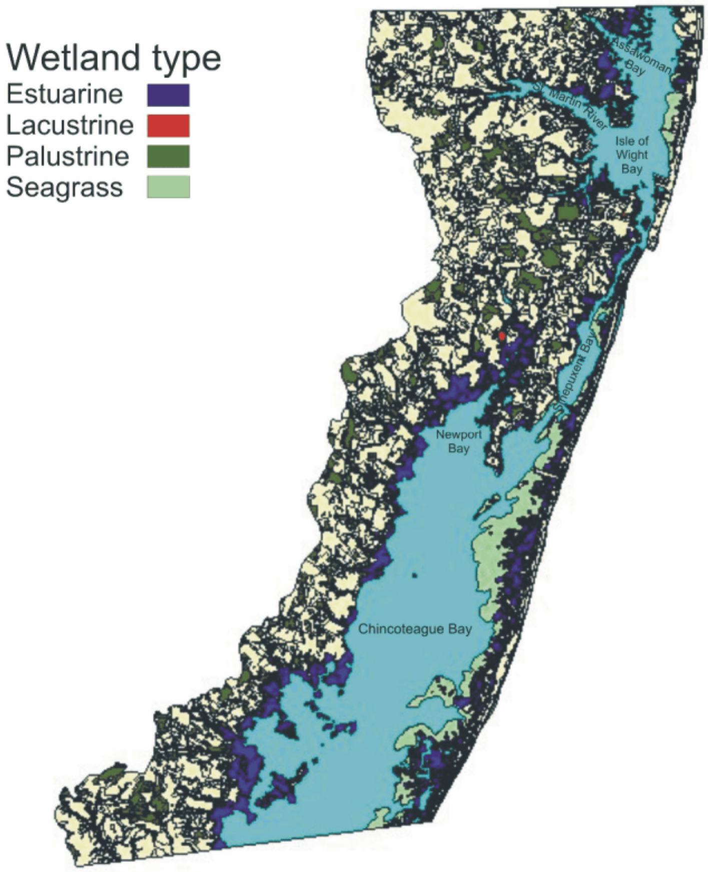

Figure 6.4.1: Map showing existing wetlands as of 2000. Estuarine wetlands are tidally influenced and contain salt or brackish water. Lacustrine wetlands are lakes or deep ponds. Palustrine wetlands are tidal and non-tidal freshwater wetlands located on floodplains associated with rivers and streams, upland depressions, and in flats between drainage systems. Seagrass beds were considered wetlands for the purposes of this report. Map reproduced from Tiner et al. 2000.

Chapter 6.5

Status of shoreline in the Maryland Coastal Bays

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Abstract

Natural shoreline habitat loss is prevalent in the Coastal Bays. Natural shoreline is important habitat for fish, shellfish, horseshoe crabs, and birds. The northernmost Coastal Bays (Assawoman Bay, Isle of Wight Bay, and the St. Martin River) have the greatest percentages of disturbed shoreline, ranging from 21 to 44 percent. Little shoreline disturbance has occurred in the three southernmost bays (Sinepuxent Bay, Newport Bay, and Chincoteague Bay). The percentage of hardened shoreline may be greater, particularly in the northern bays, due to shortcomings in shoreline classification and aerial photography. A more precise and current shoreline inventory is currently in development.

Data Analyses

The Maryland Geological Survey (MGS) has recently acquired a digital set of historical shorelines for the coastal regions of Maryland. For the Coastal Bays, the most recent of these shorelines was interpreted from digital orthophotography flown on April 12, 1989. Shoreline segments were classified by the following four shoreline types: beach, (manmade) structure, vegetated, or water's edge. The last was a catchall category, applied when none of the others was clearly discernible (Hennessee 2001).

For purposes of this report, "disturbed shoreline" is considered the equivalent of "structure." The other three shoreline types are considered "natural shoreline." "Structure" includes only hardened shorelines – bulkheads, revetments, etc. In the orthophotographs, these appear as comparatively straight stretches of shoreline flanked by convoluted reaches typical of natural shorelines. Shoreline intentionally protected by non-structural erosion control techniques, like vegetative buffers, was classified as one of the other types.

***Draft* Shoreline Indicator:** Percent natural shoreline

Results

Status of Natural Shoreline Habitat

The total shoreline miles bordering each of the Coastal Bays and the percentage of each shoreline type are shown in Table 6.5.1 (Hennessee and Stot 1999; Hennessee et. al. 2002). Figure 6.5.1 shows the same information graphically.

Table 6.5.1: Percent area classified as natural shoreline in each bay segment.

Bay Segment	% natural shoreline
Assawoman Bay	79
St. Martin River	77
Isle of Wight	56
Sinepuxent	94
Newport	100
Chincoteague	99

Summary

In 1989, the northernmost Coastal Bays, Assawoman Bay, Isle of Wight Bay, and the St. Martin River, had the greatest percentage of protected/disturbed shoreline, ranging from 21 to 44 percent. Little or no shoreline in the three southernmost bays, Sinepuxent Bay, Newport Bay, and Chincoteague Bay, was protected or disturbed at that time. Depending on the actual nature of the shoreline classified as "water's edge," the percentage of protected shoreline may be greater, particularly in the northern bays. Based on comments from several data set users who were familiar with local shoreline conditions, photo interpretation of shoreline type generally underestimated the length of hardened shoreline. In addition, the photos used were almost 15 years old and much shoreline hardening has occurred since then hence, the actual current length of hardened shoreline is believed to be greater than reported here.

Through a grant from Maryland's Coastal Zone Management Program (CZM), the Virginia Institute of Marine Science (VIMS) is in the process of generating a shoreline inventory of coastal localities in Maryland. The assessment is based on a division of the shore zone into three regions: the immediate riparian zone, the bank, and the shoreline. Characteristics of the three zones are observed from a small boat navigating along the shoreline and logged using hand-held GPS units. In the immediate riparian zone, land use adjacent to the bank is classified as one of eleven categories (forest, scrub-shrub, grass, agriculture, residential, commercial, industrial, bare, timbered, paved, or unknown). Banks are evaluated for height, stability, cover, and natural protection. Along the shoreline, VIMS notes the presence of shore protection and recreational structures (VIMS, 2004). VIMS' reports, maps, and data sets are available digitally (VIMS 2004).

To date, VIMS has completed inventories for Dorchester and St. Mary's Counties. CZM expects an inventory for Worcester County to be completed by Winter 2005 (Luscher 2004) Thereafter, CZM intends to update the survey by using aerial photography and developing a tracking database for permits issued for construction along the shore.

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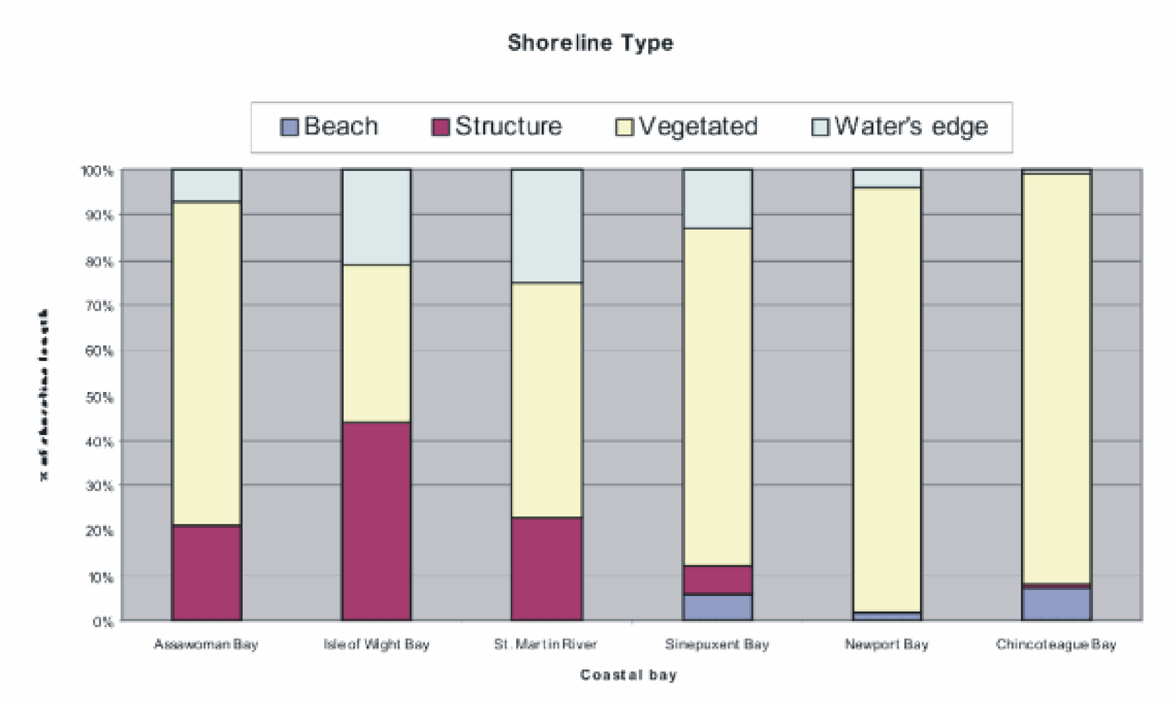

Figure 6.5.1: Total shoreline miles and percentage of each shoreline type per Coastal Bays segment. Based on DNR survey in 1989.

Section 7: Harmful algae blooms in the Maryland Coastal Bays

General Introduction

Harmful algae blooms (HABs) are being reported with increasing frequency worldwide. The presence of such blooms has produced economic losses related to decreased recreational and commercial fishing, declines in tourism, public illness, medical treatment costs, and increased expenditures for monitoring programs diverted from other programs (Bushaw-Newton and Sellner 1999). Thirteen potentially harmful algae species that have been identified in the Coastal Bays: *Aureococcus anophagefferens* (brown tide), *Pfiesteria piscicida, P. shumwayae, Chattonella* cf. *verruculosa, Heterosigma akashiwo*, *Fibrocapsa japonica*, *Prorocentrum minimum, Dinophysis acuminata.*, *Amphidinium operculatum*, *Pseudo-nitzchia* sp., *Karlodinium micrum,* and two macroalgae genera (*Gracilaria* and *Chaetomorpha*)

Algae may become harmful if they occur in an exceptionally large abundance that can result in low oxygen conditions and decreased light to underwater grasses. Also, some species of algae produce toxins affecting aquatic living resources or human health. Some high biomass blooms may produce surface scums, wash up on shore producing noxious odors, or otherwise become aesthetically unpleasing. Fish and shellfish kills may result from low oxygen conditions while some HABs interfere with the feeding or breathing of fish and shellfish. **Of the approximately 200 species of algae presently recognized though the Coastal Bays monitoring program, roughly five percent are believed to have the ability to produce toxic substances**. The following chapters outline the results of monitoring for these potentially harmful organisms. Brown tide receives special treatment because of recent large-scale blooms in the Coastal Bays.

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Chapter 7.1

Abundance and frequency of occurrence of brown tide, *Aureococcus anophagefferens*, in the Maryland 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 first discovered in Maryland during 1998, though recent research indicates that it was present since at least 1993. 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, occurring at category 3 levels in at least one Coastal Bays segment annually since 1999.

Introduction

Brown tide**,** *Aureococcus anophagefferens***,** blooms can have serious impacts on shellfish populations (scallops, hard clams, and mussels) and seagrasses. Brown tides of this species have occurred 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 during 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.

Monitoring

Since 1999, the Maryland Department of Natural Resources' brown tide (BT) program monitored 15 stations throughout the Coastal Bays. Results revealed that blooms tend to occur in late spring and early summer (May-July). Brown tide was found in all Coastal Bays segments, however, an area in the southern bays from Newport Bay to Public Landing across to Tingles Island consistently had the highest levels. Scientists classify BT blooms similar to hurricanes Category 1, 2 and 3 (Gastrich and Wazniak 2000) with 3 having the most serious environmental impacts (Table 7.1.1).

Table 7.1.1: Brown tide categories and potential ecological 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	$\geq$ 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.

Analysis

Water samples from existing Maryland Department of Natural Resources (DNR) and Assateague Island National Seashore (ASIS) stations were tested for brown tide during putative bloom season from 1999 through 2001 (Figure 7.1.1). Brown tide season was considered to be late May through mid-July. Since 2001, DNR has added late September through early November as a possible second annual season for brown tide. Samples were microscopically counted for brown tide concentration by A. Hertzig at the American Academy of Natural Science Estuarine Research Center. Peak brown tide concentrations for each of the three years were averaged for each sample station, categorized as per Table 7.1.1, and reported as the three-year brown tide status for each station. Results from 2002 and 2003 sample years are reported in the following text, but were not a part of the status calculation.

Results

Bloom intensity and distribution varied annually across the Coastal Bays. The three-year status of maximum blooms is presented as a summary (Figure 7.1.1). More about annual and interannual variability is available from DNR datasets (Wazniak 2004).

Descriptions of the blooms in each of the years monitored through 2003 are given below. All station locations refer to those shown in Figure 7.1.1.

1999 Category 2 blooms were broadly distributed including Montego Bay, Ocean Pines canal, and all of the southern bays. A Category 3 bloom in Newport Bay produced the highest concentrations of the year in mid-June (>450,000 cells*ml^{-1}); lowest concentrations were found in Virginia (Figure 7.1.2). Blooms peaked between late May and mid-June depending on area (differences between north and south) and ended in early July. Highest brown tide concentration was observed in Newport Bay in mid-June (>450,000 cells*ml^{-1}).

2000 No significant blooms were detected in the northern bays while Category 3 blooms were found in Newport Bay and at Public Landing and Tingles Island stations (Figure 7.1.3). Bloom levels peaked at the end of May and declined by the end of June. The highest concentration was observed at Public Landing on May 29 (~900,000 cells*ml^{-1}).

2001 No significant blooms were found in the Northern Bays while Category 3 blooms were detected at Newport Bay and Public Landing, and Category 2 at Tingles Island stations (Figure 7.1.4). Bloom levels peaked in mid-June and ended in late June. The highest concentration was observed at Public Landing on June 13 (680,793 cells*ml^{-1}).

2002 Category 2 blooms were extensive throughout the bays except at Nixon, VA, Taylors Landing, and XDN7646 (Figure 7.1.5). Blooms peaked late May to mid-June and ended by late June. The highest concentrations were observed at an aquaculture facility in Chincoteague Bay, where a Category 3 bloom occurred (>200,000 cells*ml^{-1}; note that the aquaculture facility is not the Public Landing station indicated on Figure 7.1.1). All-time high levels for the monitoring program were measured in Isle of Wight (XDN3445) and Manklin Creek (MKL0010).

2003 No significant blooms were found in the northern Coastal Bays. In contrast, the southern bays experienced the most spatially and temporally extensive bloom since the beginning of the monitoring program in a year where no other areas in the northeastern U.S. experienced brown tides. This bloom peaked in June and ended in mid-July. The highest concentration was at Green Point on June 10 (745,408 cells*ml^{-1}) (Figure 7.1.6). Record high concentrations were observed in the southern bays (Ferry Landing, Green Point, Taylors Landing, Pirate Islands, and Nixon, VA). (Figure 7.1.6)

Summary

During the last several years, brown tide was the predominant harmful algal bloom species, exceeding published threshold levels (Gastrich and Wazniak 2002) in the Coastal Bays from 1999 through 2003. In 2000, 2001 and 2003 no significant blooms were observed in the northern Bays while the southern Bays experienced Category 3 blooms.

The years 1999 and 2002 had category 2 blooms in the northern and southern bays. The southern bays were affected by Category 3 blooms every study year. In 2003, an extensive bloom (temporally and spatially) occurred in the southern bays when no other area in the northeastern United States reported brown tides.

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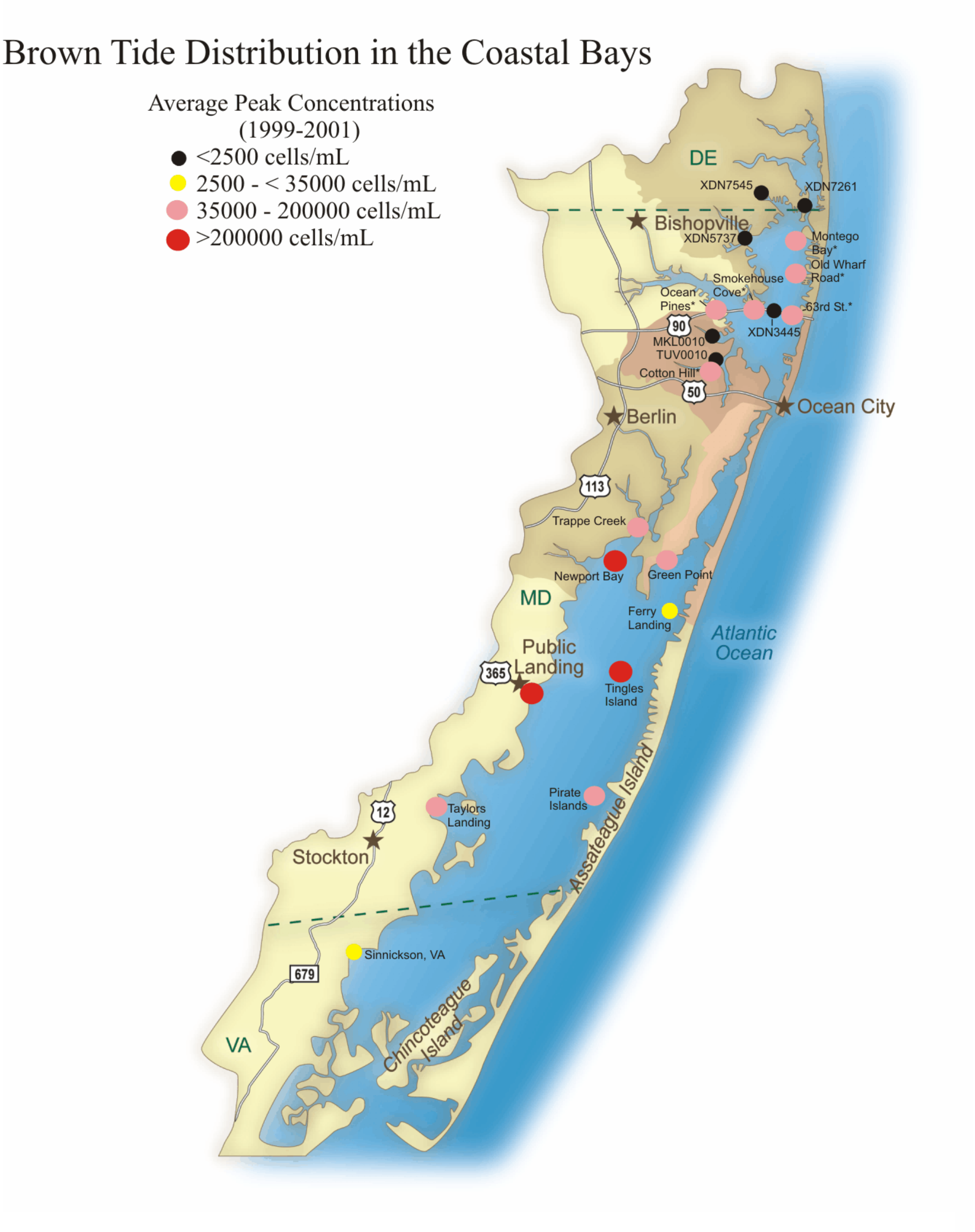


Figure 7.1.1: Average peak concentration of brown tide cells at each Coastal Bays sample station between 1999 and 2001.

Figure 7.1.2: Brown tide concentration at each Coastal Bays sample station during 1999.

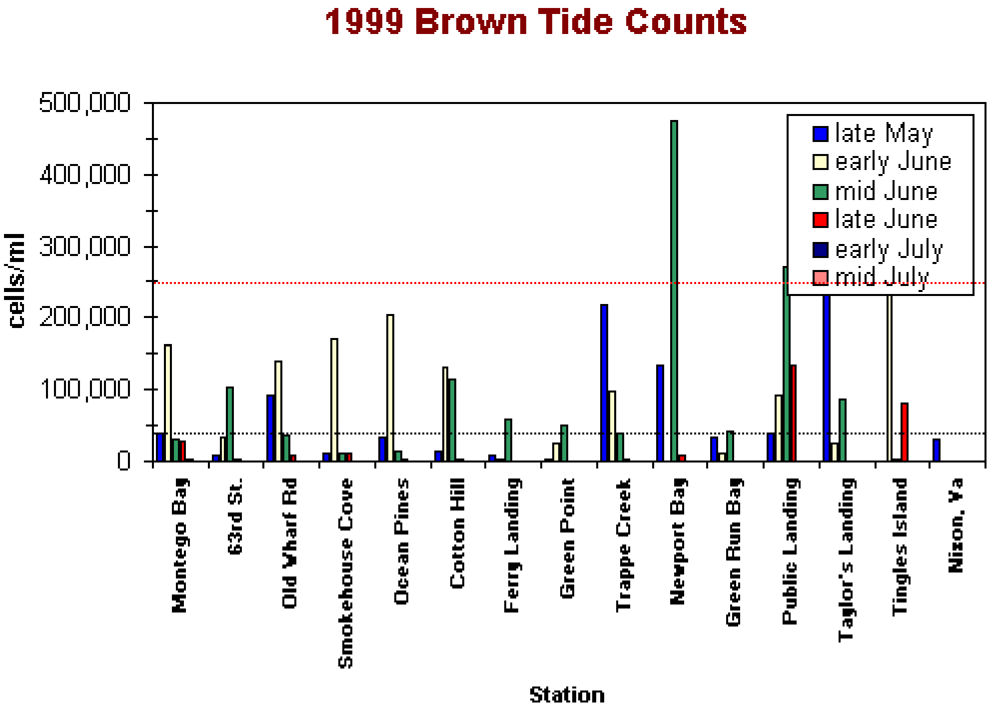


Figure 7.1.3: Brown tide concentration at each Coastal Bays sample station during 2000.

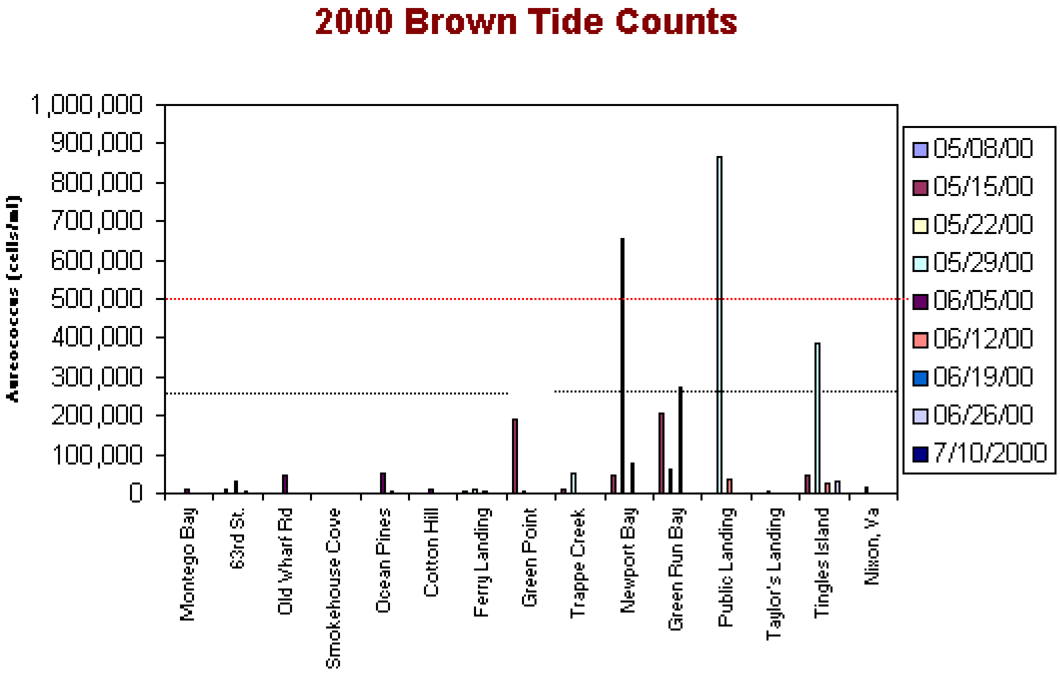


Figure 7.1.4: Brown tide concentration at each Coastal Bays sample station during 2001.

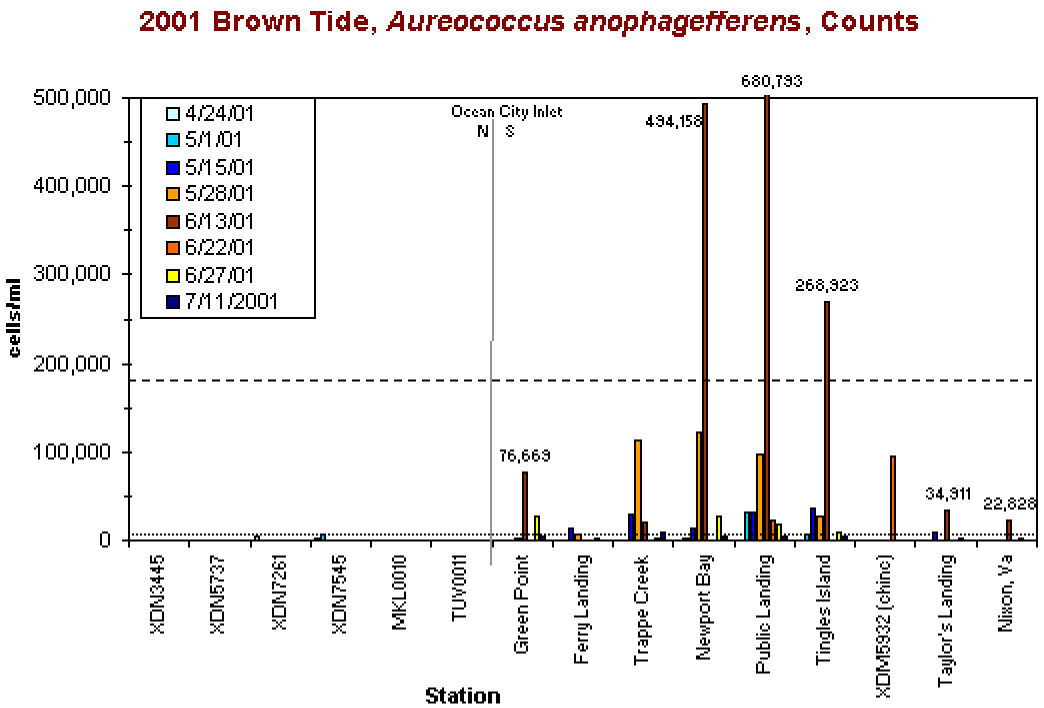


Figure 7.1.5: Brown tide concentration at each Coastal Bays sample station during 2002.

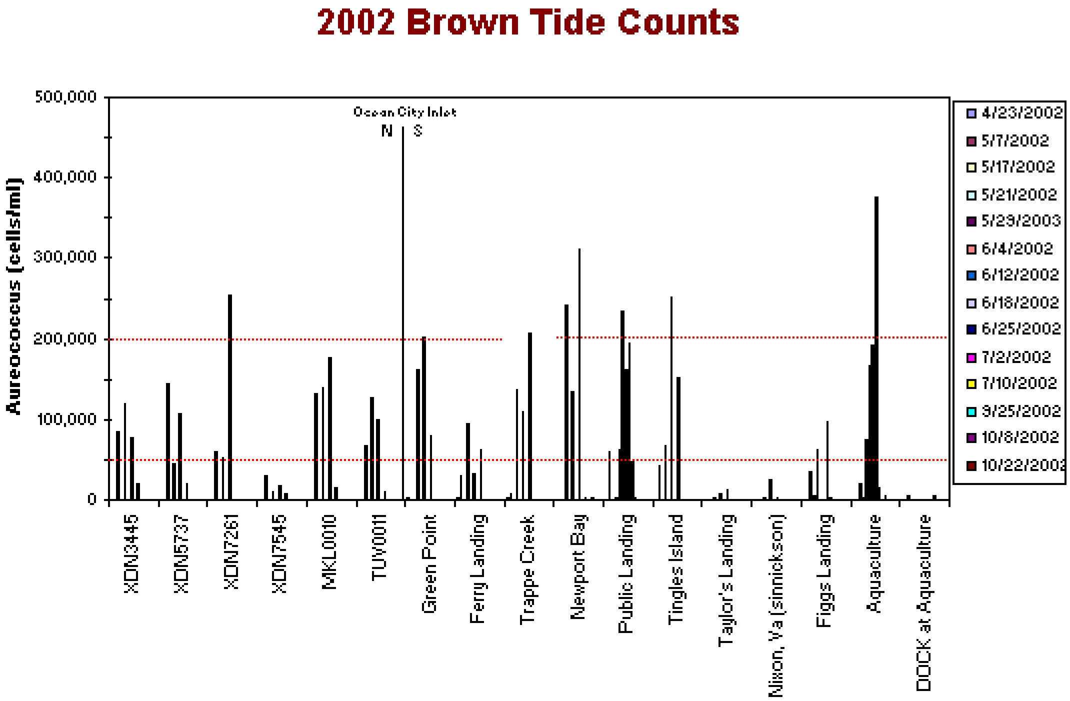
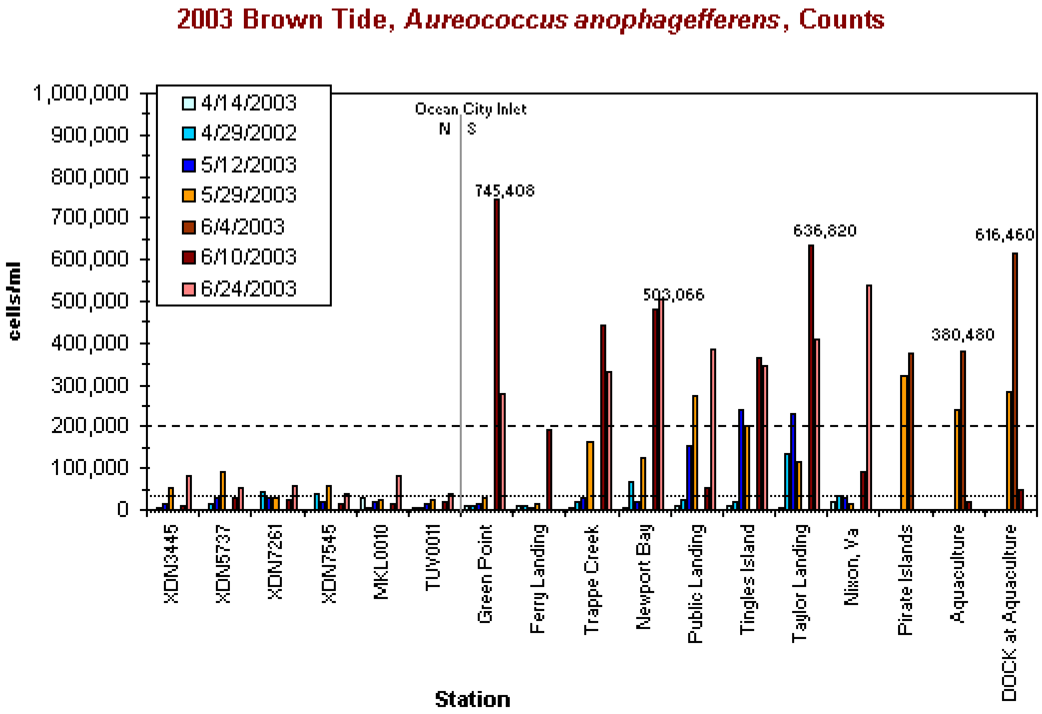


Figure 7.1.6: Brown tide concentration at each Coastal Bays sample station during 2003.



Chapter 7.2

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*, *Chattonella* spp., *Heterosigma akashiwo*, *Fibrocapsa japonica*, *Prorocentrum minimum*, *Dinophysis* spp., *Amphidinium* spp., *Pseudo-nitzchia* spp., *Karlodinium micrum,* and two macroalgae genera (*Gracilaria* and *Chaetomorpha*). The greatest number of species occurred in the polluted tributaries of the St. Martin River and Newport Bay. Approximately five percent of the phytoplankton species identified in the Maryland 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 capable of negatively affecting light and dissolved oxygen resources. 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 seagrass 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. 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 causing a large historical fish kill on the Indian River, Delaware. Similarly *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 within 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 an HAB) or if they produce a toxin that can harm aquatic life or humans. HABs are increasing worldwide. Many have been related to increases in aquatic nutrient concentrations from human activities. Blooms of harmful algae can potentially cause economic losses related to decreased recreational and commercial fishing, and tourism.

Data sets

Biomonitoring programs identify species and estimate abundance of algae through light microscope counts and genetic probe technologies. Routine samples were collected monthly at a subset of Maryland Department of Natural Resources (DNR) fixed water quality monitoring stations (Figure 7.2.1). There are recognized thresholds for some HABs from regions in the world where particular algal species have presented chronic problems to human health and the environment. Such threshold levels have been used by managers or industries to initiate shellfish fishery and recreational beach closures, and to intensify monitoring, including toxin testing. Toxin testing may proceed if human or living resource impacts are observed (Table 7.2.1). While no algae has shown toxicity from Maryland's Coastal Bays, some of the same organisms have proven to be toxic along the eastern seaboard, in particular in the Chesapeake and Delaware bays.

Draft **HAB Indicator:** Threshold exceedances

Data analysis

The list of HABs and published thresholds of management interest were used in this analysis as a means of producing an environmental indicator for tracking by site, watershed, and the Coastal Bays overall. Threshold level exceedances of abundance measured in samples for each recognized HAB species in the region were based on routine phytoplankton monitoring program results (Table 7.2.1). For some species, no density threshold exists.

Table 7.2.1: Summary of harmful algae species present in the Coastal Bays and associated threshold levels.

Species	**Abundance Threshold**	**Comments**
Aureococcus anophagefferens	Category 1 < 35,000 Category 2 $\geq$ 35,000 and $\leq$ 200,000 Category 3 > 200,000	Gastrich and Wazniak 2000
Chattonella cf. *verrculosa*	10,000 cells*ml^{-1} (Test for brevetoxin)	Estimated based on the 2000 Rehoboth Bay fish kill that included brevetoxin detection. Bourdelais et al. 2002.
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.
Fibrocapsa japonica	None available, (Test for fibrocapsin or toxic bioassay).	
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
Dinophysis sp.	5 cells*ml^{-1} Test for okadaic acid. (Some international standards available)	Levels that can initiate further testing for toxins around the world.
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
Amphidinium sp.	None available. Test for ciguatera toxin*.	**Amphidinium* has been found toxic in subtropical and tropical waters, not yet at temperate latitudes.
Karlodinium micrum *Microcystis aeruginosa*	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.
Macroalgae	No threshold	

Results

Results are summarized by station in Figure 7.2.1 and by taxonomic group in the following text.

I. Raphidophytes: *Chattonella*, *Heterosigma*, and *Fibrocapsa*

The Raphidophyte group contains 12 known species. Four have been identified from the Coastal Bays: *Chattonella* cf. *verruculosa,C. subsalsa*, *Heterosigma akashiwo*, and *Fibrocapsa japonica*. Strains of *Chattonella cf. verruculosa, H. akashiwo,* and *F. japonica* have demonstrated toxic activity elsewhere in the world. **However, there was no evidence of toxins from any Raphidophyte in Maryland tidewaters.**

Chattonella

There are two species of *Chattonella* known in the Coastal Bays, *Chattonella cf. verruculosa* (may produce toxin), and *C. subsalsa* (not known to produce toxin). *Chattonella cf. verruculosa* is a potentially toxic species that has been implicated in causing fish kills as near as the Delaware Coastal Bays and can be potentially harmful to humans when producing brevetoxins. Brevetoxin is in the same class of toxins as those produced by *Karenia brevis* (previously *Gymnodinium breve)*, an HAB species 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). *Chattonella* cf. *verruculosa* has been mainly found in Marshall Creek, Ayer Creek, and the St. Martin River.

Analysis of historic state phytoplankton data from intensive surveys of the St. Martin River in 1983 and 1992 suggested that *Chattonella cf. verruculosa*, *C. subsalsa,* and *Fibrocapsa japonica* were present in what appeared to be lower concentrations ten to twenty years ago than what was observed in recent survey years. Historical identifications were based on journal drawings of cells identified in the Maryland Department of Environment monitoring program.

What follows are brief descriptions of HAB monitoring findings from recent years:

2000 A toxic bloom of *C. cf. verruculosa* was detected in the Delaware Bays and correlated with a fish kill event and persistence of brevetoxin in the water. *Chattonella* was detected but not in a toxic state in Maryland. The presence of *Chattonella* cf. *verruculosa* in Delaware coastal waters was the first published account of the organism in U.S. coastal waters.

2001 In late June 2001 low levels were detected in Ayer, Newport, Trappe, Marshall and St. Martin Creek, however, identification was to genus level.

2002 In late May, *Chattonella* was present in Marshall Creek in low numbers(<1/ml). In early July, *Chattonella cf. verruculosa* was present in the St. Martin River, as well as Ayer, Trappe and Marshall Creeks. The densities for *Chattonella cf. verruculosa* in St. Martin River were 106 cells/ml (XDN4797) and 2,491 cells/ml (XDM4486). The Marshall Creek sample had approximately 2,000 cells*ml^{-1} of *C. cf. verruculosa* and one of the Ayer Creek samples had approximately 900 cells*ml^{-1} (Figure 7.2.1) with no evidence of impaired fish health. Lower concentrations of *C. verruculosa* were found at the other Ayer Creek and Trappe Creek sites. During a fish kill on Massey's Branch, August 17, 2002, a large bloom of *C. subsalsa* (nontoxic) was present at approximately 10,000 cells*ml^{-1} with very little potentially toxic *C. cf. verruculosa* at the site. No evidence of toxicity was detected and hypoxic dissolved oxygen conditions were noted. On August 21, *C. subsalsa* was present in Marshall Creek and Newport Creek. In September 2002, routine monitoring of the St. Martin River found *C. cf. verruculosa* concentrations at approximately 10,000 cells*ml^{-1} (approaching threshold conditions) and ~3,000 cells*ml^{-1} in Marshall Creek, but no suggestions of toxic activity or signs of fish in distress were observed. Samples collected from Marshall Creek in October 2002 showed no toxic activity in laboratory testing.

2003 *Chattonella cf. verruculosa* was present at elevated densities of 18,815 cells/ml on August 6, 2003 in the St. Martin River, well above threshold concentrations (Figure 7.2.1). This station is the site of DNR's continuous water quality monitoring meter in Bishopville Prong on the upper St. Martin River. Again, no fish kills were reported in this region coincident with elevated *Chattonella* concentrations, possibly due to an extended summer period of chronic hypoxic to anoxic dissolved oxygen levels limiting fish community persistence.

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 mariculture fish kills. No documented effects to humans were evident from such blooms.

2002 On April 24, *H. akashiwo* was detected at 1961 cells*ml^{-1} in the Newport

Bay watershed.

2003 *H. akashiwo* was detected in Newport Bay from May through September and one time in November in the St. Martin River. Abundances exceeded 1,000 cells*ml-1 in Newport Bay on June 18, (7,685 and 4,240 cells*ml^{-1}), September 10, (6,095 cells*ml^{-1}) and September 30 (4558 cells*ml^{-1}), with no evidence of toxic activity.

Fibrocapsa

Fibrocapsa has had devastating impacts on mariculture operations in Japan. Strains of *Fibrocapsa japonica* collected from the North Sea in Europe have been capable of producing toxin that killed fish in laboratory tank studies. The body tissues 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.

2002 In May, *Fibrocapsa* was present in the St. Martin River. The densities for *Fibrocapsa japonica* were 53 cells*ml^{-1} (station XDN4797) and 159 cells*ml^{-1} (station XDM4486). *Fibrocapsa japonica* was collected in low to moderate densities during June through August 2002 from the St. Martin River ($\leq$ 583 cells*ml^{-1}). *Fibrocapsa* was detected once each on Newport Creek and Trappe Creek in 2002 at low densities (53 cells*ml^{-1}). Fish populations sampled at the same time and locations as the algal samples were all healthy.

2003 *Fibrocapsa* was detected in low concentrations on July 29 in the St. Martin River (53 cells*ml^{-1}) and Newport Bay (53 cells*ml^{-1}).

II. *Pfiesteria: P. piscidia and P. shumwayae*

There are two species of *Pfiesteria, Pfiesteria piscicida* and *Pfiesteria shumwayae,* both of which are potentially toxic to fish and people. *Pfiesteria* species have 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 Maryland Department of the Environment and Department of Natural Resources have examined fish kills and fish health events (distressed fish or fish with lesions reported) 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* was predominantly in the Newport Bay system (Ayer, Trappe, Marshall, and Newport Creeks).

2000 *Pfiesteria* was detected at fish health events in Ayer, Trappe, Marshall, and Newport Creeks (stations AYR0017, NEWPCT5, TRC0024, TRC0031, and MSL0011; note that NEWPCT5, TRC0024, and TRC0031 do not appear on Figure 7.2.1, but refer to fish kill sites on Newport and Trappe Creeks).

2001 *Pfiesteria* was first detected on Trappe Creek in June at station XCM4878 (positive for *P. piscicida* and negative for *P. shumwayae*). In July, *Pfiesteria* was also detected in Ayer, Trappe, and Newport Creeks (stations AYR0017, NEWPCT5, TRC0024, and TRC0031). In August, *Pfiesteria* was recorded in Ayer, Trappe, and Marshall Creeks (stations AYR0017, NEWPCT5, TRC0024, TRC0031, and MSL0011). Fish samples (menhaden;*Brevoortia tyrannus*) collected in Ayer and Newport Creeks were healthy. No menhaden were captured on Trappe or Marshall Creeks.

2002 *P. piscicida* was found in Ayer Creek, Newport Bay, and the St. Martin River (one occurrence each). *Pfiesteria* sp. was first seen in Newport Bay in March. In late June, it was detected in Ayer Creek and in late July, *Pfiesteria* was present in Trappe Creek (upstream and downstream of its confluence with Ayer Creek). In August sampling of Newport Creek (due to a small fish kill) and Marshall Creek / Massey Branch revealed *P. piscicida* present at both stations on Newport Creek and all three stations on Marshall Creek / Massey Branch. Both *Pfiesteria* species were identified in association with the lesioned menhaden in Turville Creek in late September and early October. Fish bioassays were negative for toxicity for a sample containing *P. shumwayae*, collected on September 25.

2003 In 2003, two water column samples tested positive for *P. piscicida* in the Newport Bay watershed. *P. shumwayae* was not detected in routine water column sampling during 2003.

Sediment *Pfiesteria* results

Between 1999 and 2002, a north to south gradient in *Pfiesteria* detections occurred in sediment samples with no *Pfiesteria* detected in sediment of the St. Martin River, 8 percent of samples on the Herring/Turville Creeks (*P. piscicida* only), 17 percent on Trappe Creek (*P. shumwayae* only), and 87 percent of samples from Marshall Creek had one or both species of *Pfiesteria* (Table 7.2.2). Both species were also detected in the sediments of Scarboro Creek. No significant relationships with *Pfiesteria* presence and sediment composition have been found (Trice 2004).

Table 7.2.2: 2003 Sediment *Pfiesteria* results showing the presence of *Pfiesteria piscicida* (pisc) and *Pfiesteria shumwayae* (shum).

Tributary	**none**	**pisc**	**shum**	**pisc&shum**
Marshall	3	4	12	5
Saint Martins	12			
Scarboro Creek	2		3	
Trappe Creek	10		2	

III. *Prorocentrum*

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 positive 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 was suspected in declines of seagrass in the mid-Chesapeake Bay region during 2001.

Effects on bay organisms were identified at concentrations as low as 3,000 cells* ml^{-1} (EPA 2003) providing a threshold for tracking and assessing blooms. Threshold exceedances were recorded once each year during 2001 and 2002 in samples from the St. Martin River. Brief descriptions of Prorocentrum findings from the DNR phytoplankton monitoring program are given below (bolded values indicate threshold exceedences).

2001 *Prorocentrum minimum* was detected on Bishopville Prong in April at densities of **5,459 cells*ml^{-1}** (Figure 7.2.1). All other detections were < 3,000 cells*ml^{-1} and typically < 1,000 cells*ml^{-1}.

2002 *P. minimum* was found in the St. Martin River and Turville and Herring Creeks during the spring (April and May). Most concentrations were low (under 3,500 cells*ml^{-1}) and were not considered to be a public health threat since the river was closed to shellfish harvesting. However, one sample on the St. Martin River on April 29 had a density of **21,253 cells*ml^{-1}** (station XDM4486) (Figure 7.2.1). Levels < 3,000 cells*ml^{-1} were detected in the Newport Bay watershed, and additional detections were made in the St. Martin River.

2003 In 2003, no sample collected was above 2,809 cells*ml^{-1} (April 28; station XDN4312).

IV. *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*). All are known to produce okadaic acid or other toxins causing diarrhetic shellfish poisoning (DSP) (Marshall 1996). DSP has occurred in humans consuming 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 when *Dinophysis* is present include intensified monitoring of shellfish harvest waters, toxin testing of the shellfish, and application of restrictions or closures of 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 were 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 ten times the minimum used in Europe (i.e., 0.5 x 10 = 5 cells*ml^{-1}) has been implemented as a tracking indicator for this species, given the lack of evidence for toxic effects by the genus to the East Coast of the United States. *Dinophysis* has been observed above threshold concentrations in Assawoman Bay (once in 2001, once in 2003), Isle of Wight (once in 2002), and the St. Martin River (once in 2001, seven times in 2002, and twice in 2003). However, no evidence exists demonstrating toxicity to date in the Coastal Bays systems. Brief descriptions of *Dinophysis* detection in Coastal Bays samples follow.

2001 In 2001, *D. acuminata* was detected on May 22 (station XDM4486 at 1 cell*ml^{-1}) in the St. Martin River and *Dinophysis* sp. on December 17 (XDN3445 at 1 cell*ml^{-1}) in Assawoman Bay. No exceedances of the threshold were detected.

2002 During 2002, one sample from January 22 on St. Martin Creek contained 1 cell*ml^{-1}. Two samples from St. Martin Creek contained *D. acuminata* at 1 cell*ml^{-1} (station XDN4797) and 4 cells*ml-1 (station XDM4486) in March. In April, *Dinophysis acuminata* was identified at all three phytoplankton stations in the St. Martin River. Station XDN4312 had

$2*ml^{-1}$ and station XDN4797 had $6*ml^{-1}$. Station XDM4486 had 1 cell $*ml^{-1}$. In May, *Dinophysis* was also found in the St. Martin River and in Herring and Turville Creeks. The greatest concentrations of *Dinophysis* (up to 10 cells$*ml^{-1}$) were found in areas closed to shellfish fishing (St. Martin, Turville, and Herring Creeks). For perspective, the Canada action threshold for *Dinophysis* is considered 5 cells$*ml^{-1}$. Low concentrations (up to 2 cells$*ml^{-1}$) were observed in the Isle of Wight (Figure 7.2.1).

2003 In 2003, *D. acuminata* was detected only in December and collected from station XDN4797 (St. Martin Creek on December 2) with **10 cells$*ml^{-1}$** and station XDN3445 (Little Assawoman Bay on December 1) with **8 cells $*ml^{-1}$** (Figure 7.2.1).

V. *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 DA. 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.

Pseudo-nitzschia cell densities of 200 cells$*ml^{-1}$ *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 $> 5 \times 10^5$ 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).

Between 2001-2003, no samples obtained from the Coastal Bays contained *Pseudo-nitzschia* >106 cells$*ml^{-1}$.

VI. *Amphidinium*

The algae *Amphidinium operculatum* is an epibenthic dinoflagellate. This species was 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. There is no evidence of toxicity for this species in the Coastal Bays.

VII. *Karlodinium micrum*

Karlodinium micrum may cause water to become discolored a reddish-brown, known as a mahogany tide. Mahogany tides may 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 was 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. 2002). No human health effects have been associated with blooms of *K. micrum*. Brief descriptions of annual *K. micrum* detection in Coastal Bays samples follow.

<u>2001</u> *K. micrum* was detected in St. Martin River, Little Assawoman Bay, and Newport Creek (identified as *G. estuariale*) always at concentrations less than 10,000 cells*ml^{-1}.

<u>2002</u> *K. micrum* was detected in St. Martin River, Isle of Wight Bay, and Assawoman Bay and Newport Creek less than or equal to 1,696 cells*ml^{-1} in all samples.

<u>2003</u> *K. micrum* was detected in St. Martin River, Isle of Wight Bay, and Newport Bay watersheds at less than or equal to 1,696 cells*ml^{-1} in all samples, well below threshold levels of concern for living resources

VIII. *Microcystis aeruginosa*

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 sublethal 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).

Cyanophyte (bluegreen algae) concentrations at Bishopville Prong, Trappe Creek, and

Ayer Creek have all shown declines from any pre-2000 phytoplankton sampling.

IX. Potentially harmful macroalgae

Macroalgae are considered harmful by the National Oceanographic and Atmospheric Administration (NOAA) when they produce dense overgrowth in localized areas, such as coastal embayments, that receive 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 decrease dissolved oxygen (Bushaw-Newton and Sellner 1999). Further, large increases in macroalgal may be evidence of a seagrass dominant system balancing on the edge of a eutrophic state (Valliela et al. 1997).

Two genera of macroalgae are believed to qualify as HABs, under NOAA's definition, in specific areas of the Coastal Bays. First, *Gracilaria* in Turville Creek was so dense in 1999-2001 that it caused the DNR fishery monitoring program to relocate a monitoring station in operation for more than 25 years. This system is prone to low dissolved oxygen levels that are probably influenced by these blooms. Furthermore, total maximum daily load (TMDL) models of this system were insufficient in predicting the low dissolved oxygen, likely because they failed to incorporate primary producers other that phytoplankton. Second, *Chaetomorpha* levels in Chincoteague Bay were so dense from 1998 through 2001 they are believed to have impacted scallop restoration efforts and seagrass density in some areas (Orth 2004, Tarnowski 2004).

Summary

HAB species are recognized for their potentially toxic properties as well as their ability to produce large blooms negatively affecting light and dissolved oxygen resources. Approximately five percent of the phytoplankton community identified for Maryland's Coastal Bays was comprised of HAB species. Table 7.2.3 summarizes the HAB species found at each station from 1988 through 2003. 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 seagrass distribution and growth (see Chapter 7.1). 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 acuminate,* 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 fish kill on the Indian River, Delaware. Similarly *Chattonella* cf. *verruculosa* was implicated in a large fish kill and persistent brevetoxins detected in Delaware's Rehoboth Bay during 2000. Tracking HAB species diversity, abundance, distribution, and toxic activity through time will provide important indicators of environmental change for the Coastal Bays.

Thirteen potentially harmful algae species have been identified in the Coastal Bays. These include *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*). Presence of HAB species has been most diverse (i.e., greatest richness of HAB species) in polluted tributaries of the St. Martin River and Newport Bay (Figure 7.2.1).

Threshold exceedances included *C. cf. verruculosa* in September 2002 on St. Martin River. A bloom of *C. cf. verruculosa* during 1999 in the 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 in the St. Martin River. *Heterosigma akashiwo* blooms of 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* was present in the Coastal Bays, but no known cell density thresholds were available to estimate possible effects or warrant intensified surveys for this species.

Dinophysis was observed above threshold concentrations in Assawoman Bay (once in 2001, once in 2003), Isle of Wight (once in 2002), and the St. Martin River (once in 2001, seven times in 2002, and twice in 2003). However, there was no evidence for toxicity to date in the Coastal Bays systems. All samples could potentially warrant intensified monitoring for toxins, but 5 cells*ml^{-1} is probably a more appropriate threshold.

Between 2001-2003, no samples from the Coastal Bays exceeded suggested living resource effects levels of $\geq$ 10,000 cells*ml^{-1} for *K. micrum* or 200 cells*ml^{-1} for *Pseudo-nitzschia sp.*. Bluegreen algae were encountered, but declined compared with pre-2000 data. Rarity of *Microcystis aeruginosa* was likely due to limited freshwater and low salinity habitat for this species.

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Table 7.2.3: Potential HAB species found at each sampling station from 1988 through 2003. For a discussion of brown tide, see Chapter 7.1.

Station	**Potential HAB species**	**Station**	**Potential HAB species**
XDN6454	Brown tide *Karlodinium micrum* *Prorocentrum minimum*	TUV0019	Brown tide *Dinophysis acuminata* *Heterosigma akashiwo* *Prorocentrum minimum*
XDM4486	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Dinophysis acuminata* *Fribrocapsa japonica* *Heterosigma akashiwo* *Karlodinium micrum* *Prorocentrum minimum* *Pfiesteria sp.*	AYR0017	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Karlodinium micrum* *Heterosigma akashiwo* *Microcystis sp.* *Prorocentrum minimum*
XDN4797	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Dinophysis acuminata* *Fibrocapsa japonica* *Heterosigma sp.* *Karlodinium micrum* *Prorocentrum minimum*	TRC0043	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Heterosigma akashiwo* *Karlodinium micrum* *Microcystis sp.* *Prorocentrum minimum*
XDN4312	Brown tide *Chattonella cf. verruculosa* *Dinophysis acuminata* *Heterosigma sp.* *Karlodinium micrum* *Prorocentrum minimum*	NPC0012	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Heterosigma akashiwo* *Karlodinium micrum* *Microcystis sp.* *Prorocentrum minimum*
XDN3724	Brown tide	MSL0011	Brown tide *Chattonella cf. verruculosa* *Chattonella subsalsa* *Heterosigma akashiwo* *Karlodinium micrum* *Prorocentrum minimum*
XDN3527	*Chattonella cf. verruculosa* *Fibrocapsa japonica* *Heterosigma akashiwo* *Karlodinium micrum*	XCM0159	Brown tide *Prorocentrum minimum*
XDN3445	Brown tide *Dinophysis acuminata* *Karlodinium micrum* *Pseudo-nitzschia*	XBM1301	Brown tide
TUV0011	Brown tide *Chattonella cf. verruculosa* *Karlodinium micrum* *Prorocentrum minimum* *Pseudo-nitzchia*		

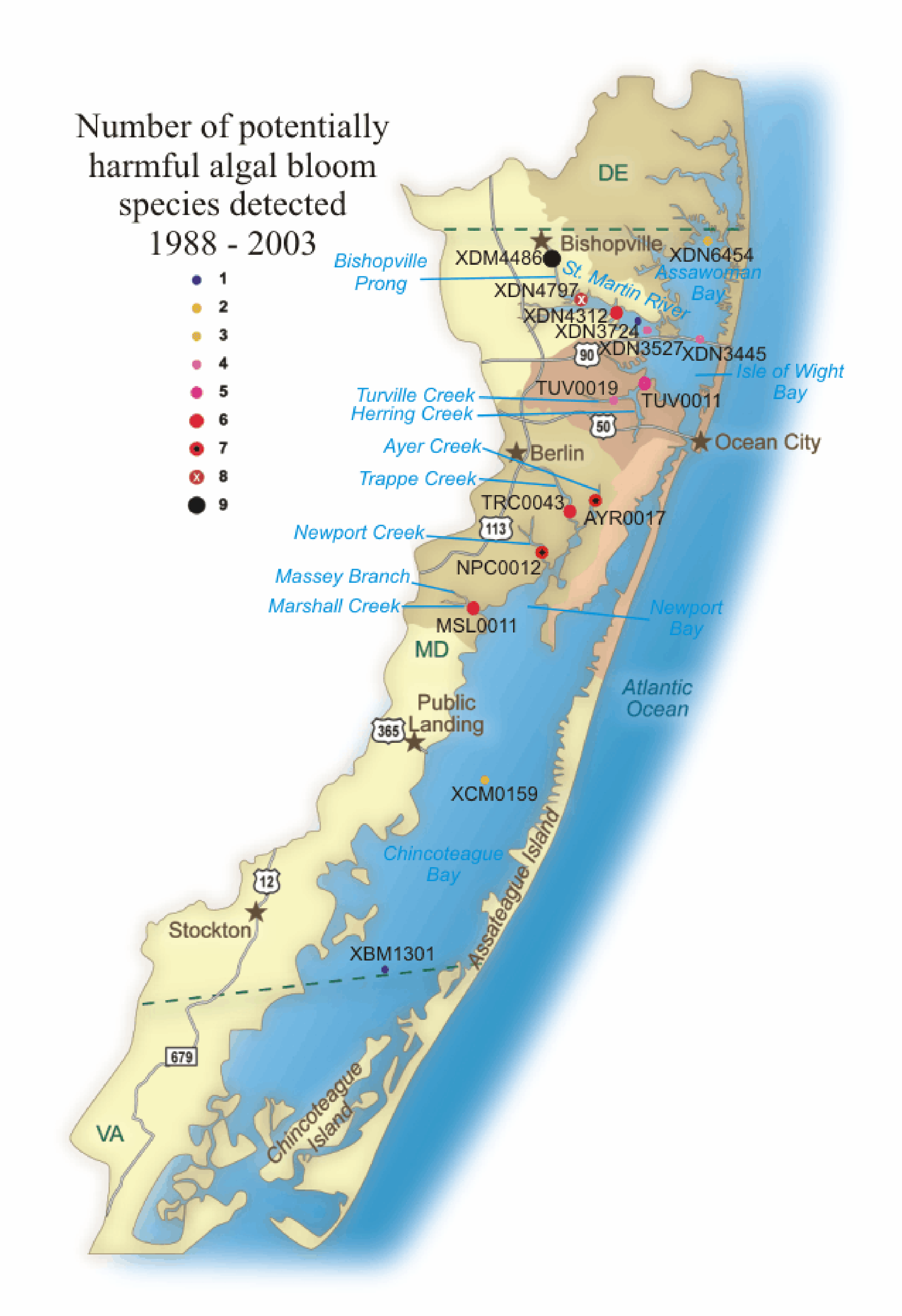

Figure 7.2.1: Locations of HAB sampling stations from 1988 through 2003. The number of potentially HAB species for each station is also indicated. Pertinent place names mentioned in the text are also shown in blue italics.

Section 8: Status of living resources in the Maryland Coastal Bays

General Introduction

Healthy populations of living resources in the Coastal Bays are vital. Phytoplankton are an important component of the base of the food web. Fish populations are ecologically and economically important, while shellfish (hard clams, scallops) also play an important role in filtering the bay. There is evidence that seagrasses and shellfish exist in a synergistic relationship in which the shellfish help to maintain water clarity necessary for the grasses to become established, and both are important in providing habitat for juvenile fish. The grasses enhance water clarity with their baffling effects, and their root masses serve to protect shellfish from predators. The following chapters each deal with one of these many living resources components.

Chapter 8.1

Analysis of phytoplankton populations in the Maryland Coastal Bays

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Abstract

Phytoplankton populations were analyzed for current status (2001-2003) as well as long-term trend (1983-2003) at several Coastal Bays water monitoring stations. Status was assessed for the winter, spring, summer, and fall seasons, while trends were assessed for July, August, and September only. For the Coastal Bays overall, phytoflagellates, diatoms, and dinoflagellates dominated spring and summer seasons from 2001 through 2003. The fall was strongly dominated by phytoflagellates, with diatoms and cryptophytes also appearing at relatively high levels. Highest diversity was observed during winter when samples were dominated by phytoflagellates and diatoms. Status at individual stations varied. Trend analyses indicated an overall reduction in phytoplankton abundance in the St. Martin River, while phytoplankton density increased in tributaries of the Isle of Wight Bay. Blue-green algae declined, while raphidophyte populations increased, in Newport Bay and the upper tributaries of the St. Martin River.

Introduction

Phytoplankton**,** or algae, are a natural and critical part of aquatic ecosystems. Algae, like terrestrial plants, capture the sun's energy and support the food web that leads to fish and shellfish. They occur in a size range from tiny microscopic cells floating in the water column (phytoplankton) to large mats of visible macroalgae that grow on bottom sediments.

Presently, there are fourteen stations sampled for phytoplankton in the Coastal Bays (Figure 8.1.1). Phytoplankton sampling in the Coastal Bays began in 1983 as part of an intensive survey to assess nutrient loading to the St. Martin River. This survey was performed in the summer on slack tide. In 1992, the survey was repeated to assess the expansion of the Ocean Pines sewage treatment plant (STP) on the St. Martin River. In 1998, tributaries considered to have similar chemistry to those where *Pfiesteria* was found in 1997 were sampled, including the St. Martin River and Trappe/Ayer's Creek watersheds in the Coastal Bays. There were three phytoplankton stations in each of the watersheds. In 2001, routine Coastal Bays sampling began and that initiative added seven stations for phytoplankton identification. There were two stations in Isle of Wight Bay, two in Chincoteague Bay, and one in each of Turville Creek, Manklin Creek, and Marshall Creek. All of these stations were sampled monthly throughout the entire year. In 2003, six of these stations were sampled weekly from May until the end of October. The subset included DNR fixed-monitoring stations TRC0043, AYR0017, NPC0012, MSL0011, TUV0011, and XDM4486 (Figure 8.1.1). This sampling was initiated to track harmful algal species in the Coastal Bays.

Indicator: None (*draft*: presence/ dominance of bluegreens)

Data sets

Data for phytoplankton trends were restricted to samples collected from July, August, and September. The data for Marshall Creek (MSL0011) was limited to three years with 16 samples collected, but 88 percent of those samples (14) were collected in 2003. Data from Turville Creek (TUV0011) and Manklin Creek (MKL0010) were collected over four years with 22 and 10 samples collected, respectively. Seventy percent of those samples that were collected in Turville Creek were collected in 2003. Data for Isle of Wight Bay (XDN3445), Assawoman Bay (XDN6454), and Chincoteague Bay (XDN5932 and XBM1301) were limited, starting in 2001 with nine samples for each location over three years. Data for Trappe Creek (TRC0043) and Ayers Creek (AYR0017) spanned six years with 30 samples collected. Data for the St. Martin River spanned eight years with 72 samples collected from five stations. The data record was not continuous over the eight years of sampling. Samples were collected in 1983 and 1992 at the same stations, then 1998 through 2003 at another set of stations. In addition, phytoplankton counts were conducted seasonally from 2001 through 2003 on samples collected from selected fixed-station water quality monitoring stations (see Section 4 and Figure 8.1.1). These counts were reviewed to assess three-year status of phytoplankton populations at the station and segment levels.

Analyses

Samples collected in plastic liter bottles were analyzed within 48 hours following sampling. One-milliliter (ml.) aliquots of the unpreserved (i.e. live), mixed samples were placed in a Sedgewick-Rafter plankton counting cell and allowed to settle for 15 minutes. Identification and counting were done with an Olympus phase-contrast compound microscope at 200X magnification. A single strip count was made. The perimeters and diagonals of the counting cell were then examined for any additional plankton forms not encountered in the strip count. These were recorded as present at cell densities of one. When necessary for identification of smaller forms, samples were examined under higher magnification. Significant blooms may have been treated with preservative on the counting chamber after identification from the live material to better estimate the densities.

Status of phytoplankton populations

Results of phytoplankton analyses for each bay segment by station follow:

Assawoman Bay

XDN6454 - Chrysophytes dominated the community in spring and declined through the remainder of the year. Diatoms made their greatest contribution in winter and remained present at about ten to fifteen percent of the community the rest of the year. Phytoflagellates were dominant in summer and fall and were then significant community components of the winter and spring. Cryptophytes achieved their greatest contributions in fall, though they were not the dominant phytoplankton. *Chrysocromulina* contributed similarly in the fall. Cyanophytes were approximately five percent of the community in winter and were rare in other seasons (Figure 8.1.3).

XDN3445 – Chrysophytes represented 31 percent of the spring community with co-dominant phytoflagellates and moderate diatom contributions. Chrysophytes declined in importance through the remainder of the year. Diatoms achieved dominance (more than half of the community) in winter. *Chrysocromulina* was present during summer, fall, and winter, with greatest importance in autumn (29 percent). Cryptophytes and dinoflagellates were present at low importance from summer into winter (Figure 8.1.4).

St. Martin River

XDN4797 – Diatoms were the winter and spring dominant plankton with persistent presence in summer and fall. Phytoflagellates dominated the summer. Cryptophytes were the dominant form of algae in the fall with nearly even contributions of chrysophytes, diatoms, and phytoflagellates comprising most of the rest of the autumn community. Cyanophytes contributed small proportions to the community in all seasons with greatest abundance in the summer (roughly five percent) (Figure 8.1.5).

XDM4486 – Diatoms were the winter and spring dominants, declining in importance in summer and fall. Phtyoflagellates comprised more than half of the summer community. Cryptophytes dominated in fall with significant contributions from the chrysophytes and phytoflagellates. Cryptophytes remained important in the winter. Cyanophytes were present in summer less than five percent at the same time raphidophytes (at roughly two percent of the time) were the most abundant (Figure 8.1.6).

XDN4312 - Diatoms were the winter and spring dominant plankton with persistent presence in summer and fall. Phytoflagellates dominated the summer. Cryptophytes were the dominant form of phytoplankton in the fall with nearly even contributions of chrysophytes, diatoms, and phytoflagellates comprising most of the rest of the fall community. Cyanophytes contributed small proportions to the community in all seasons with greatest abundance in the winter (roughly five percent). Winter showed greater representation of more rare components of the community (e.g., *Pyramimonas, Chrysochromulina,* Dinoflagellates) (Figure 8.1.7).

Isle of Wight Bay

TUV0016 – No winter data was collected at this station. Chrysophytes were dominant in spring (greater than fifty percent) with diatoms and phytoflagellates evenly contributing to the remainder of the community. Phytoflagellates dominated in summer with diatoms and chrysophytes evenly contributing the remainder of the summer community. Phytoflagellates comprised approximately 80 percent of the fall community at this location (Figure 8.1.8).

TUV0011 – Chrysophytes dominated the spring followed by phytoflagellates and diatoms in abundance as well. Phytoflagellates dominated in summer (62 percent) with important contributions from diatoms, chrysophytes, and, to a lesser degree, dinoflagellates. Phytoflagellates remained dominant in the fall with important contributions from diatoms, cryptophytes, and *Chrysocromulina*. Winter was dominated by phytoflagellates, but diatoms reached their greatest contribution of the year as co-dominants. Cyanophytes and chrysophytes were well represented in winter (Figure 8.1.9).

Newport Bay

TRC0043 – Diatoms dominated the spring with important contributions from cyanophytes and phytoflagellates and minor contributions from greens and chrysophytes. Phytoflagellates dominated in summer with diatoms and lesser contributions from chrysophytes and cyanophytes. Phytoflagellates dominated the fall but cryptophytes made their greatest contribution of the year. *Chrysocromulina* and dinoflagellates were common, though small, components of the community. Winter was co-dominated by diatoms and phytoflagellates, and greens were a small but significant component (Figure 8.1.10).

NPC0012 – This station was dominated by phytoflagellates year-round. Diatoms contributed their greatest percentage during winter, but varied little in their relative contribution across all seasons at this location. Chrysophytes had their greatest presence in spring and summer and were represented at lower levels in fall and winter. Cryptophytes and *Chrysocromulina* were best represented in autumn but were relatively minor with respect to dominance. Dinoflagellates were also relatively small contributors to the community in fall and winter. Cyanophytes were notably abundant during winter, nearly co-dominant with phytoflagellates. Cyanophytes remained persistent in the community, though as relatively minor contributors, during spring, summer, and fall (Figure 8.1.11).

MSL0010 – Cyanophytes made their strongest presence year-round at this site, but were never greater than 19 percent (spring). Phytoflagellates dominated the summer and fall, diatoms co-dominated with phytoflagellates in winter. Raphidophytes were best represented among the surveyed sites in this analysis; they were small components (two to three percent) of the spring and summer communities. Chrysocromulina were also important in the spring (the only site where this was evident) and to a lesser degree in the fall. Cryptophytes and greens were among the lesser representatives in the community during fall, winter, and spring. Chrysophytes were best represented in the summer but vary relatively little across seasons in the contribution to the overall community (Figure 8.1.12).

MKL0010 – Diatoms co-dominated with phytoflagellates in winter and were important during spring along with phtyoflagellates and chrysophytes. Diatoms were common to the summer and fall seasons. Cryptophytes made their strongest appearance in the fall, though only eight percent, and smaller contributions in summer and winter. Dinoflagellates were minor components of the summer, fall, and winter seasons. Cyanophytes made their greatest contributions in winter, though they were only seven percent of the community (Figure 8.1.13).

Chincoteague Bay

XBM5932 – Chrysophytes dominated in the spring, making up nearly half of the community and declining in importance through the remainder of the year. Winter season was the most diverse, with diatoms co-dominant with phytoflagellates and *Chrysocromulina*. Cyanophytes were strongest contributors in the winter making up about 12 percent of the community. Cryptophytes made their greatest contribution in the fall, but only contributed three to four percent and were lesser contributors in winter (Figure 8.1.14).

XBM1301 – Phytoflagellates co-dominated with diatoms in summer and fall. Spring was dominated by phytoflagellates, with secondary dominance divided between chrysophtes and diatoms. Cryptophytes made their greatest contribution in the fall, but only contributed three to four percent and were lesser contributors in summer and winter. Winter was again the most diverse season, with important contributions from *Chrysocromulina* and cyanophytes (Figure 8.1.15).

Trends in phytoplankton populations

The analysis of the phytoplankton community included data from July, August, and September. Variables for each station included abundance of cells per milliliter for Cyanophyta, Chlorophyta, Bacillariophyta, Pyrophyta, Raphidophyceae, Chrysophyceae, Cryptophyceae, Prymnesiaceae, Prasinophyceae, and total number. Results of the analysis by segment are described below.

St. Martin River

Phytoplankton data from the St. Martin River based primarily on cell densities showed an enriched condition in the upper river with gradually diminishing enrichment downriver. This was apparent for all years. The upper most station (Table 8.1.1) was more affected by high flow then downstream stations (Tables 8.1.2 and 8.1.3).

There was an average overall reduction of 85% in total phytoplankton cell counts from 1983-2003 (Tables 8.1.1-8.1.3).

Major groups of phytoplankton for the seven years of sampling were similar. Five taxonomic groups dominated 88 percent of the samples (72). They were, unidentified microflagellates (45%), *Paulinella ovalis* (24%), *Cyclotella* (8%), *Cylindrotheca closterium* (8%), and *Oscillatoriaceae* (4%).

The data suggested blue-greens were reducing at stations XDM4486 (Figure 8.1.16). The data also suggested Raphidophyceae were increasing at stations XDM4486 (Figure 8.1.19).

Isle of Wight Bay

The data suggested phytoplankton density was increasing in both Manklin and Turville Creeks (Figures 8.1.22 and 8.1.23). This strength of the trend was limited by the small amount of data.

Newport Bay

The data suggested blue-greens were declining at stations TRC0043 (Figure 8.1.17) and AYR0017 (Figure 8.1.18). Raphidophyceae were increasing at stations NPC0012 (Figure 8.1.20) and MSL0011 (Figure 8.1.21).

Summary

Seasonal patterns in phytoplankton community dynamics of the Coastal Bays were investigated from community composition data (Figure 8.1.6). Diatoms achieved their greatest contributions most often during winter, their next greatest contribution in spring, and were less common components of the community in summer and fall. Chrysophytes made their greatest contributions in the spring and were at times and locations dominant before declining through summer, fall, and winter.

Chrysochromulina and phytoflagellates were strong, consistent components of the year-round Coastal Bays community, typically comprising 50 percent or more of the plankton in the summer season. These taxa made lesser but significant contributions throughout the remainder of the year.

Cryptophytes, a desirable food source for many dinoflagellates, were most frequently encountered in the fall, but rarely composed more than 8-10 percent of the community. Secondarily, they contributed around two percent of the summer and winter communities when present. Their low contributions overall may be a function of grazing pressures rather than low productivity.

Raphidophytes, involving species with the potential for toxin production and blooms that could affect living resources or occasionally human health, made their strongest showing and Marshall Creek during spring and summer and were otherwise rare. Cyanophytes were most commonly winter contributors to the plankton community and rarely made up greater than five percent of the community in any season. Common potentially toxic, summer bloom-forming cyanophytes such as *Microcystis*, *Anabaena* and *Aphanizomenon* appeared rarely, not unexpectedly since they prefer largely freshwater habitats that are uncommon to the Coastal Bays tributaries. Remaining groups (i.e., Greens, Ebria+, Pyramimosa+ groups) comprised infrequent and small contributions to the community. Unclassified cells occurred most frequently during the spring. Seasonally, winter tended to show the greatest diversity of groups represented in the analysis.

Table 8.1.1: Raw phytoplankton cell counts and percent change over time for one St. Martin River station.

St. Martin River - Total Count Per Ml.

XDM4486 - July

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	1,386,271			*Cyclotella*	Low
1992	20,271	-98.5377318		*Perdinium*	Average
1998	9,966	-99.28109295	0.491638301	*Nitzschia*	High
1999	15,529	-98.87980056	1.558197873	*Nitzschia*	Low
2000	19,769	-98.57394406	1.273037543	*Oscillatoriaceae*	Low
2001	38,479	-97.2242801	1.946431281	*Paulinella ovalis*	Low
2002	258,985	-81.31786642	6.730554328	Unidentified Flagellates	Low*
2003	41,965	-96.97281412	0.162036411	Unidentified Flagellates	High*

*- Record

XDM4486 - August

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	1,228,441			Oscillatoriaceae	Low
1992	2,912	-99.76295158		Oscillatoriaceae	Average
1998	22,949	-98.13185981	7.880837912	*Paulinella ovalis*	High
1999	25,599	-97.91613924	1.115473441	*Paulinella ovalis*	Low
2000	10,815	-99.11961584	0.422477441	*Cyclotella*	Low
2001	150,310	-87.76416613	13.89828941	*Cyclotella*	Low
2002	345,322	-71.88941105	2.297398709	Unidentified Flagellates	Low*
2003	48,635	-96.0409169	0.140839564	Unidentified Flagellates	High*

*- Record

XDM4486 - September

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	2,001,762			*Cyclotella*	Low
1992	18,536	-99.07401579		*Gyrodinium uncatenum*	Average
1998	17,225	-99.13950809	0.929272767	*Paulinella ovalis*	High
1999	107,060	-94.65171184	6.215384615	*Skeletonema*	Low
2000	63,813	-96.81215849	0.596048945	Unidentified Flagellates	Low
2001	6,148	-99.69287058	0.096344005	Unidentified Flagellates	Low
2002	112,399	-94.38499682	18.2822056	Unidentified Flagellates	Low*
2003	20,135	-98.99413617	0.179138604	*Gyrodinium uncatenum*	High*

*- Record

Table 8.1.2: Raw phytoplankton cell counts and percent change over time for two St. Martin River stations.

St. Martin River - Total Count Per Ml.

XDN4506 + XDN4797 - July

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	280,340			*Cyclotella*	Low
1992	249,046	-11.16287365		Unidentified Flagellates	Average
1998	13,568	-95.16016266	0.054479895	*Nitzschia*	High
1999	12,296	-95.61389741	0.90625	*Pennales*	Low
2000	20,671	-92.62645359	1.68111581	*Paulinella ovalis*	Low
2001	4,082	-98.54391097	0.197474723	Unidentified Flagellates	Low
2002	112,908	-59.7246201	27.6599706	Unidentified Flagellates	Low*
2003	239,258	-14.65434829	2.11905268	Unidentified Flagellates	High*
					*- Record

XDN4506 + XDN4797 - August

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	256,039			Unidentified Flagellates	Low
1992	8,362	-96.73409129		*Katodinium rotundatum*	Average
1998	14,893	-94.18330801	1.781033246	*Nitzschia*	High
1999	18,391	-92.81710989	1.234875445	*Paulinella ovalis*	Low
2000	18,497	-92.77570995	1.005763689	*Paulinella ovalis*	Low
2001	16,749	-93.45841844	0.905498189	*Cyclotella*	Low
2002	43,938	-82.83933307	2.623320795	Unidentified Flagellates	Low*
2003	194,881	-23.88620484	4.435363467	Unidentified Flagellates	High*
					*- Record

XDN4506 + XDN4797 - September

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	134,085			Unidentified Flagellates	Low
1992	9,648	-92.80456427		*Paulinella ovalis*	Average
1998	19,133	-85.73069322	1.983105307	*Paulinella ovalis*	High
1999	27,348	-79.60398255	1.429362881	*Paulinella ovalis*	Low
2000	6,785	-94.93977701	0.248098581	*Paulinella ovalis*	Low
2001	6,890	-94.86146847	1.015475313	Unidentified Flagellates	Low
2002	5,777	-95.69153895	0.838461538	Unidentified Flagellates	Low*
2003	309,202	130.6014841	53.52293578	Unidentified Flagellates	High*
					*- Record

Table 8.1.3: Raw phytoplankton cell counts and percent change over time for two St. Martin River stations.

St. Martin River - Total Count Per Ml.

XDN4312+ XDN4118 - July

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	160,620			*Rhizosolenia*	Low
1992	179,287	11.62184037		Unidentified Flagellates	Average
1998	8,109	-94.95143818	0.045229158	*Nitzschia*	High
1999	8,056	-94.98443531	0.993464052	*Paulinella ovalis*	Low
2000	8,799	-94.52185282	1.092229394	*Paulinella ovalis*	Low
2001	2,120	-98.68011456	0.24093647	*Paulinella ovalis*	Low
2002	29,892	-81.38961524	14.1	Unidentified Flagellates	Low*
2003	130,645	-18.66205952	4.370567376	Unidentified Flagellates	High*
					*- Record

XDN4312+ XDN4118 - August

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	112,463			Unidentified Flagellates	Low
1992	7,145	-93.64679939		*Katodinium rotundatum*	Average
1998	13,303	-88.17122076	1.861861442	*Nitzschia*	High
1999	14,840	-86.80454905	1.115537849	*Paulinella ovalis*	Low
2000	17,543	-84.40109191	1.182142857	Unidentified Flagellates	Low
2001	13,568	-87.9355877	0.773413897	Unidentified Flagellates	Low
2002	14,893	-86.75742244	1.09765625	Unidentified Flagellates	Low*
2003	86,743	-22.86974383	5.824414154	Unidentified Flagellates	High*
					*- Record

XDN4312+ XDN4118 - September

DATE	COUNT	% CHANGE from 1983	CHANGE from Year to Year	DOMINANT TAXA	Rainfall
1983	121,676			Unidentified Flagellates	Low
1992	6,105	-94.98257668		*Paulinella ovalis*	Average
1998	11,448	-90.59140669	1.875184275	*Paulinella ovalis*	High
1999	19,879	-83.66234919	1.736460517	*Skeletonema*	Low
2000	8,109	-93.33557974	0.407917903	Unidentified Flagellates	Low
2001	5,777	-95.25214504	0.712418301	Unidentified Flagellates	Low
2002	7,526	-93.81472106	1.302752294	Unidentified Flagellates	Low*
2003	99,640	-18.11039153	13.23943662	Unidentified Flagellates	High*
					*- Record

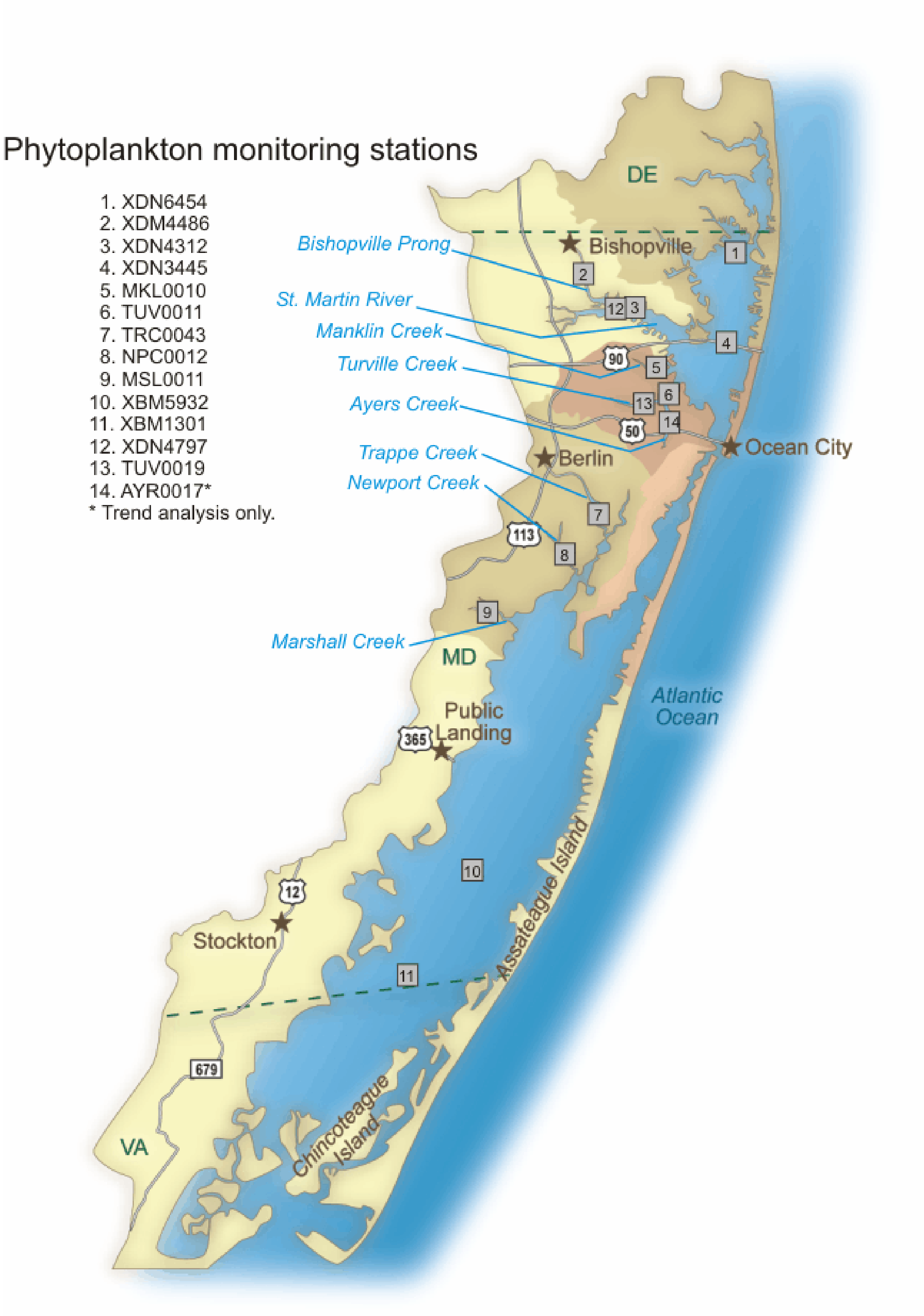

Figure 8.1.1: Location of Maryland Department of Natural Resources phytoplankton monitoring stations in the Maryland Coastal Bays.

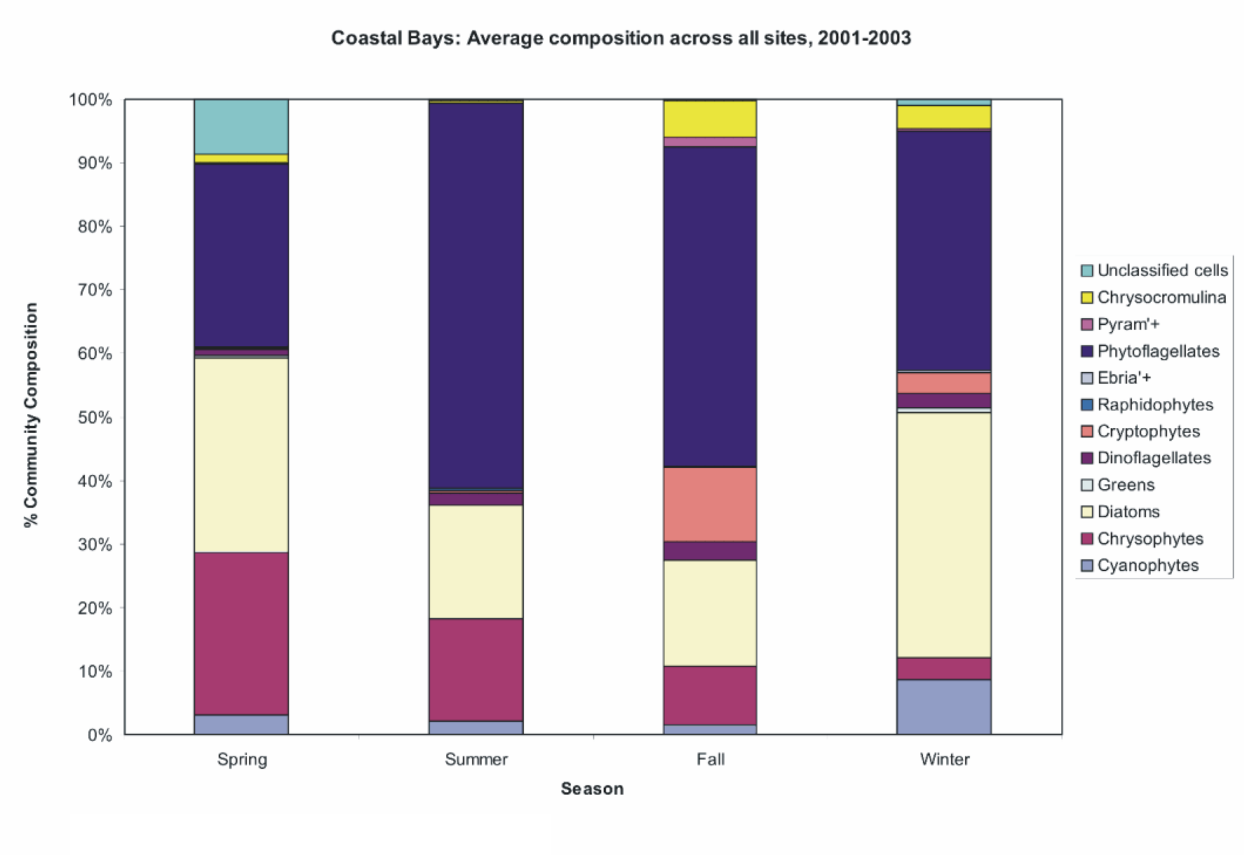

Figure 8.1.2: Total phytoplankton community over seasons.

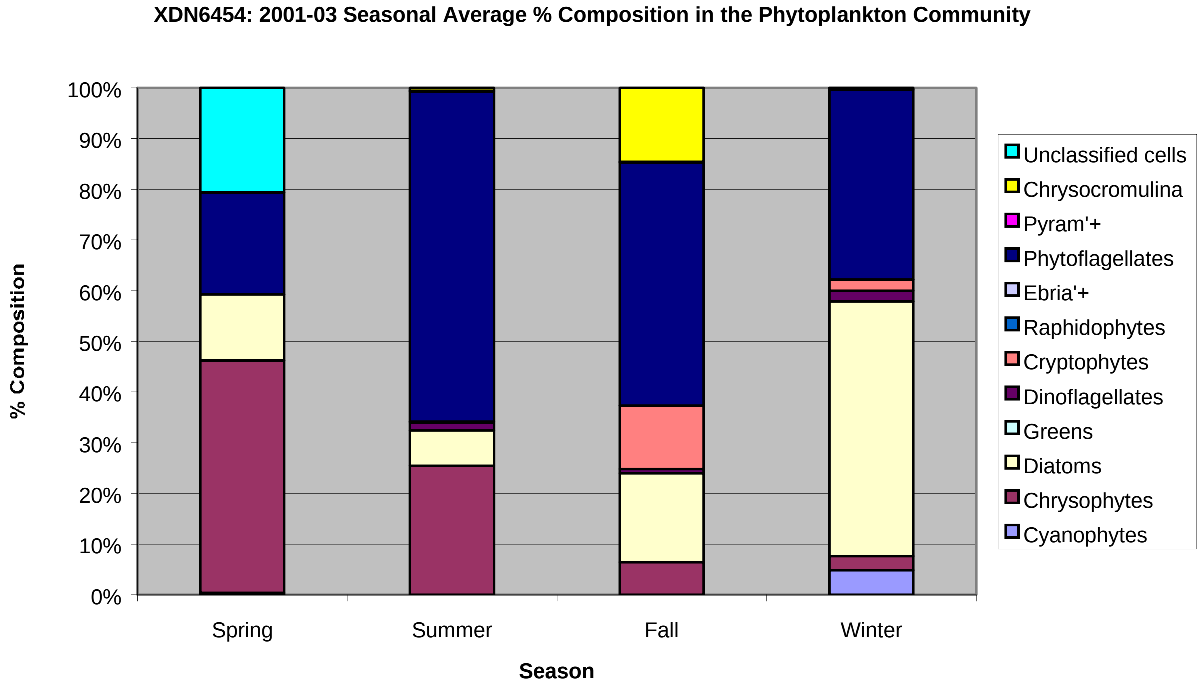

Figure 8.1.3. Phytoplankton community composition at station XDN6454 (Assawoman Bay).

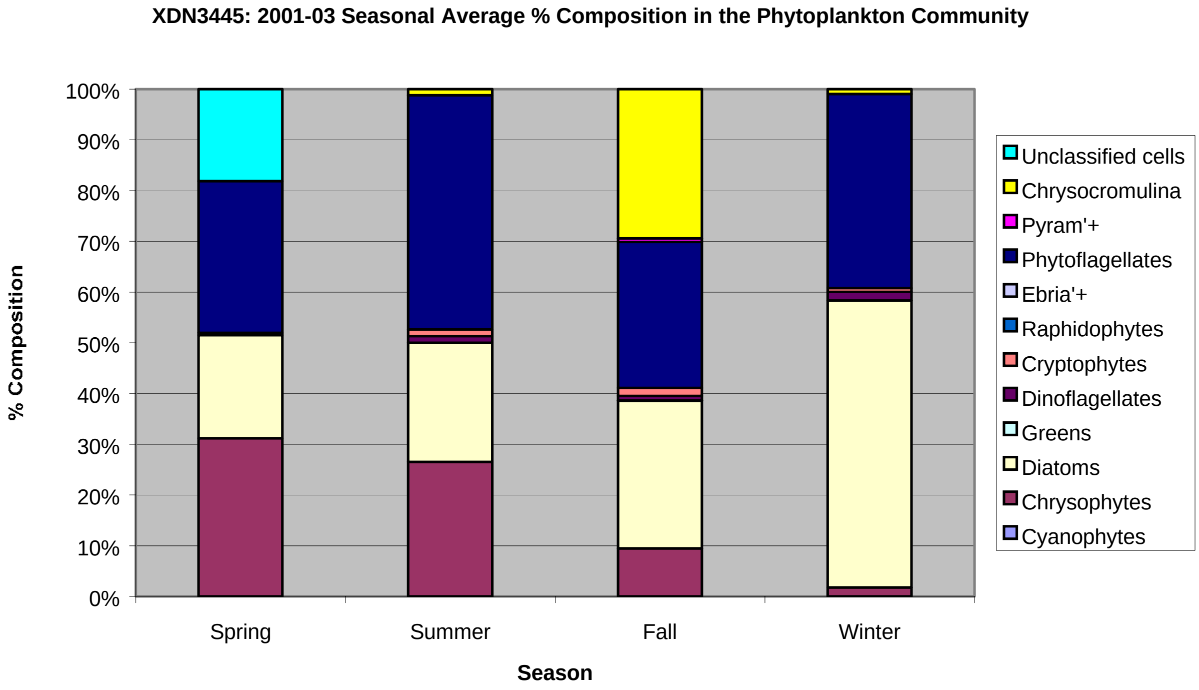

Figure 8.1.4. Phytoplankton community composition at station XDN3445 (Assawoman Bay).

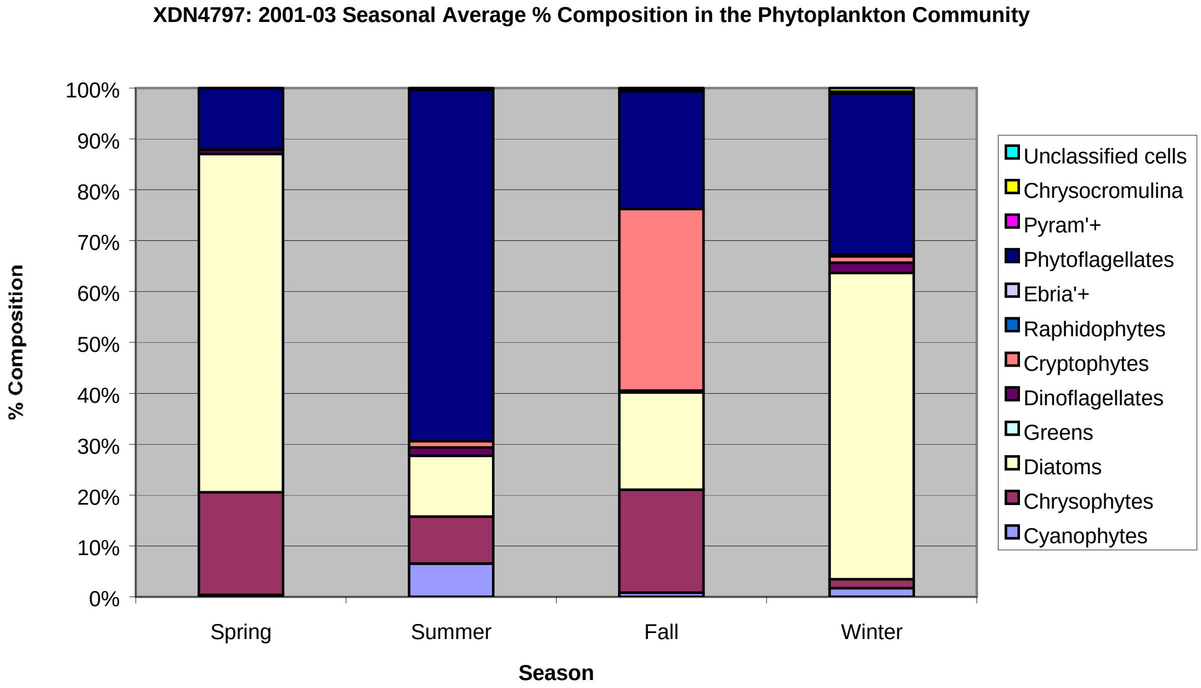

Figure 8.1.5. Phytoplankton community composition at station XDN4797 (St. Martin River).

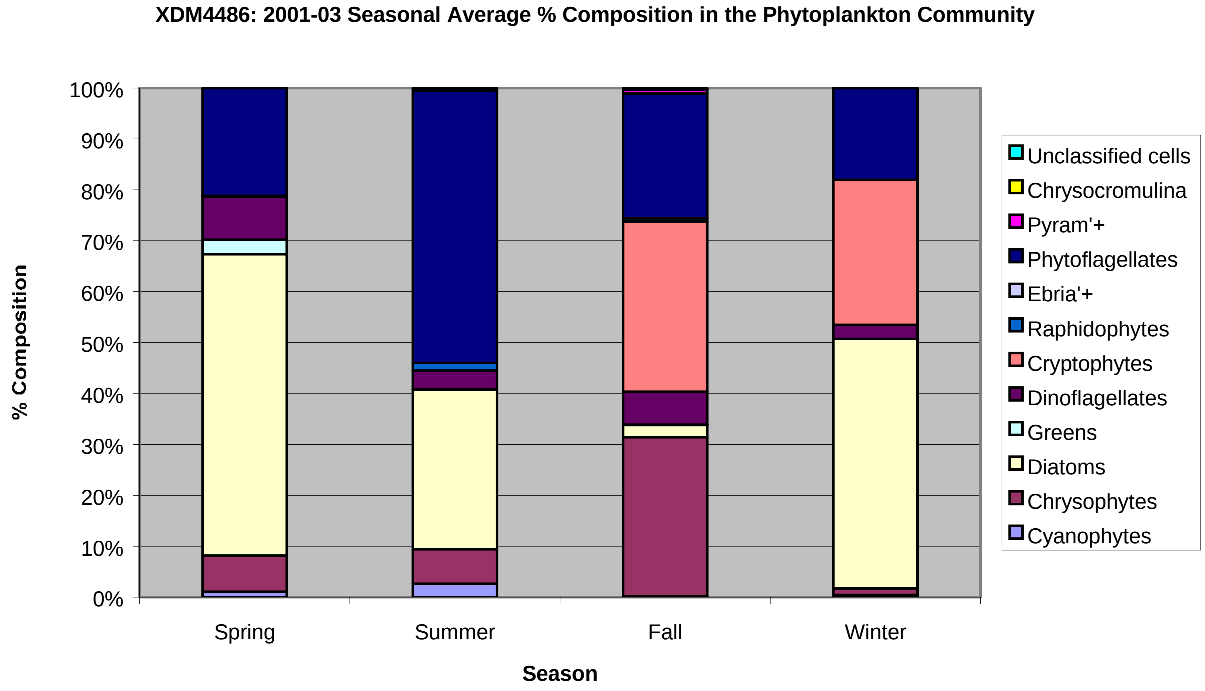

Figure 8.1.6. Phytoplankton community composition at station XDM4486 (St. Martin River).

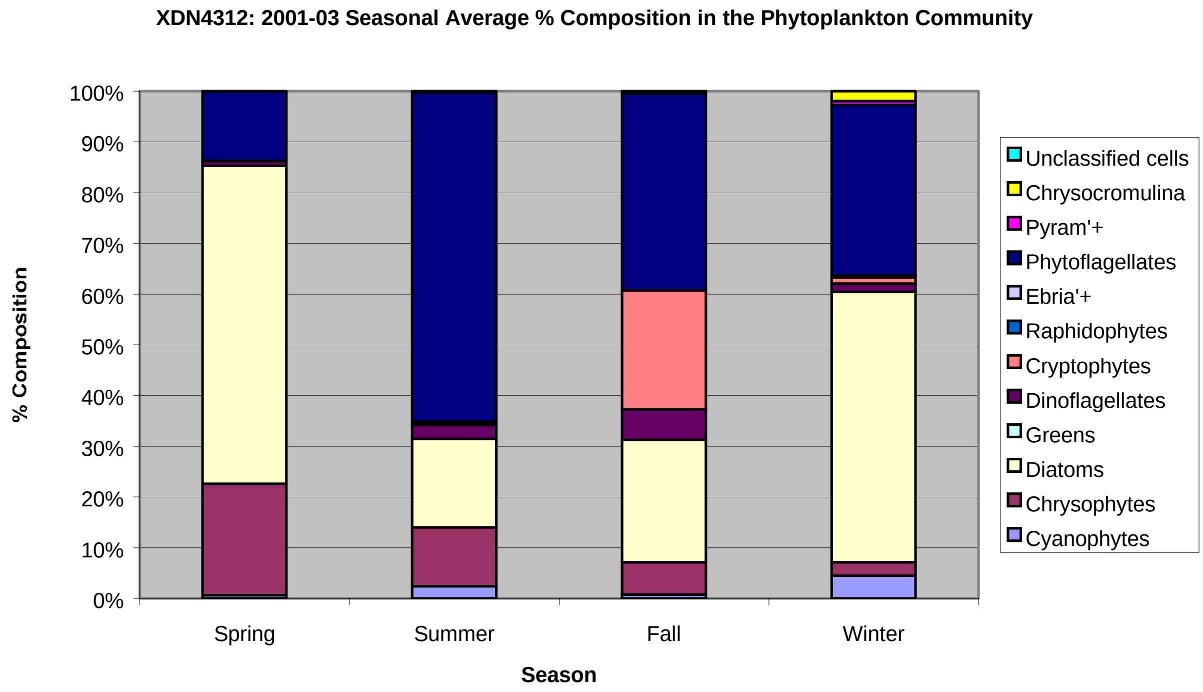

Figure 8.1.7. Phytoplankton community composition at station XDN4312 (St. Martin River).

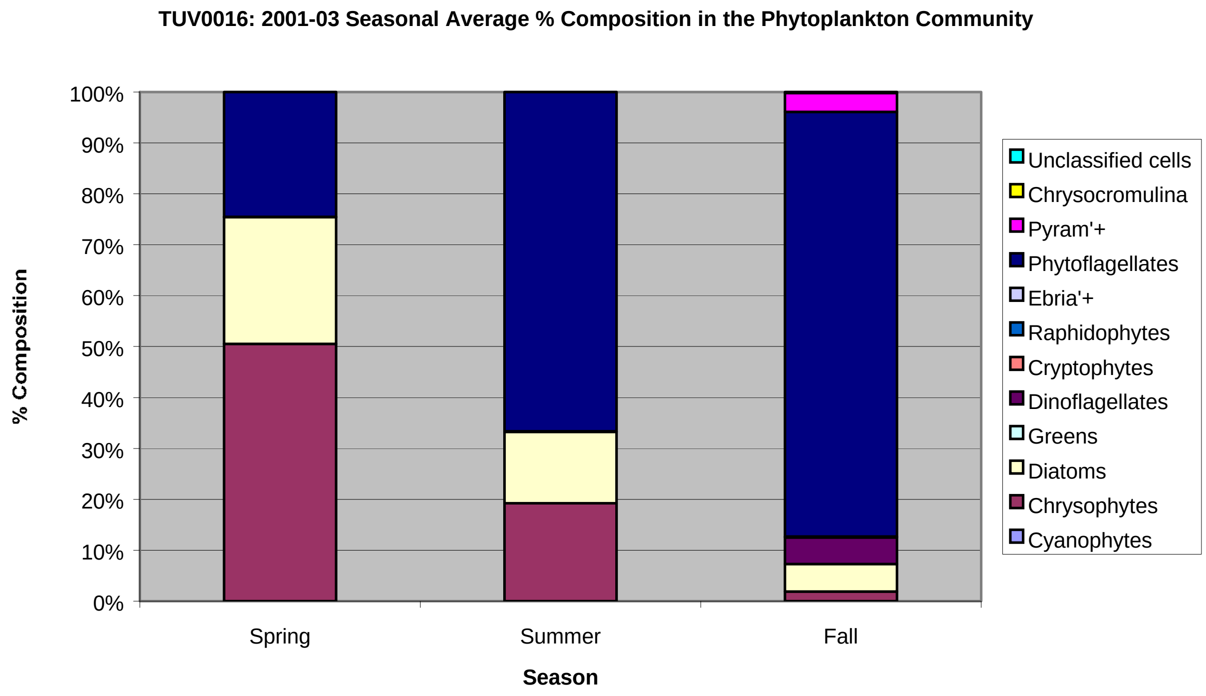

Figure 8.1.8. Phytoplankton community composition at station TUV0016 (Isle of Wight Bay).

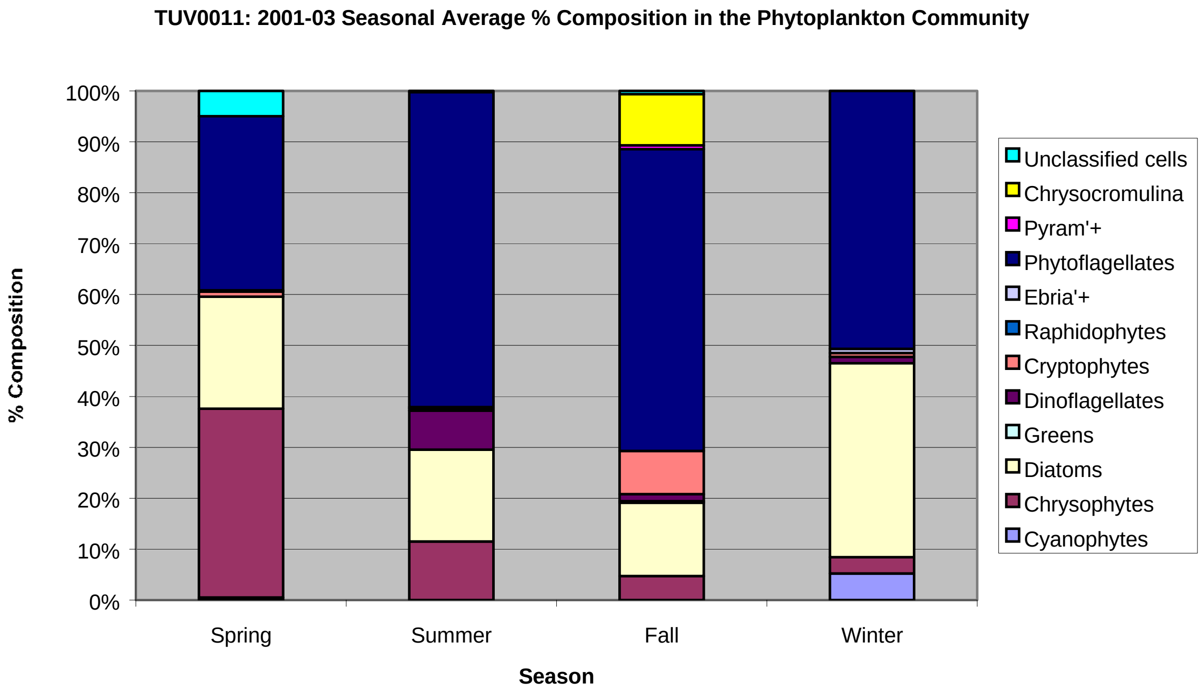

Figure 8.1.9. Phytoplankton community composition at station TUV0011 (Isle of Wight Bay).

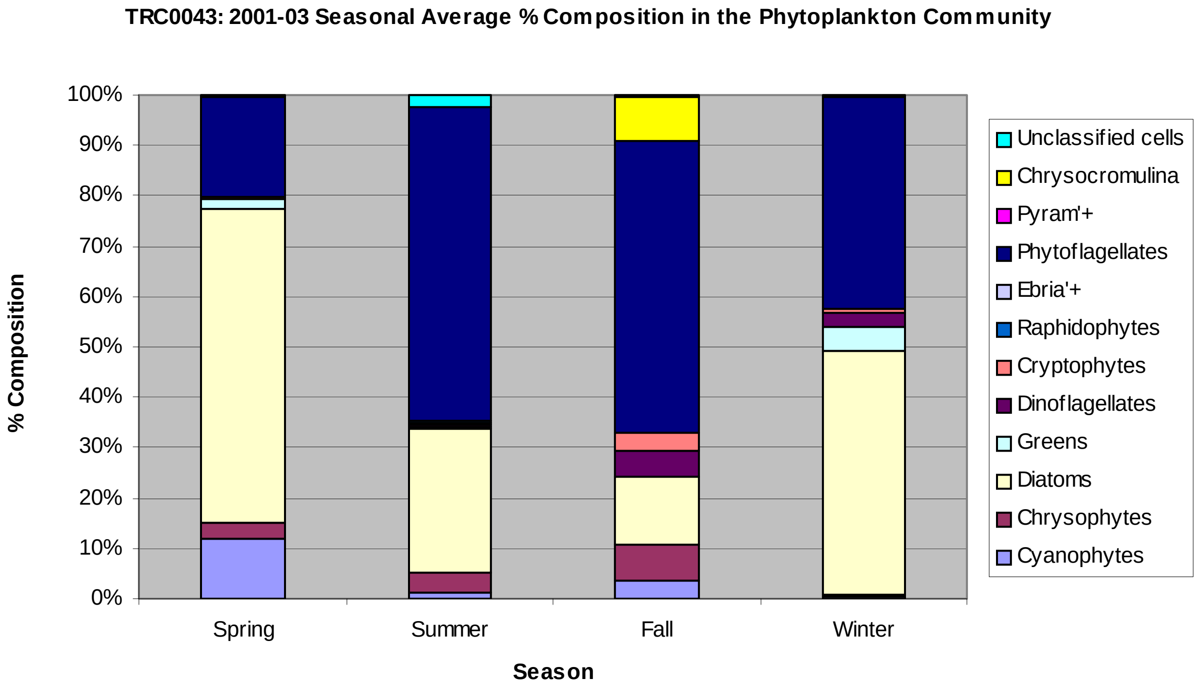

Figure 8.1.10. Phytoplankton community composition at station TRC0043 (Newport Bay).

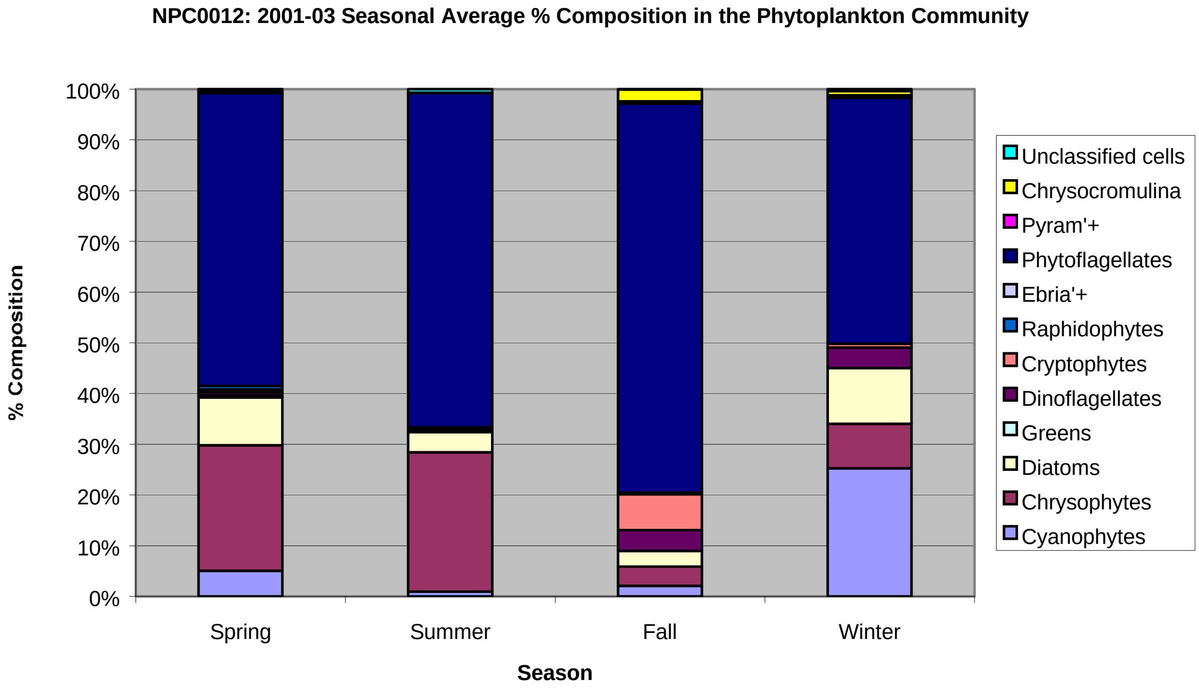

Figure 8.1.11. Phytoplankton community composition at station NPC0012 (Newport Bay).

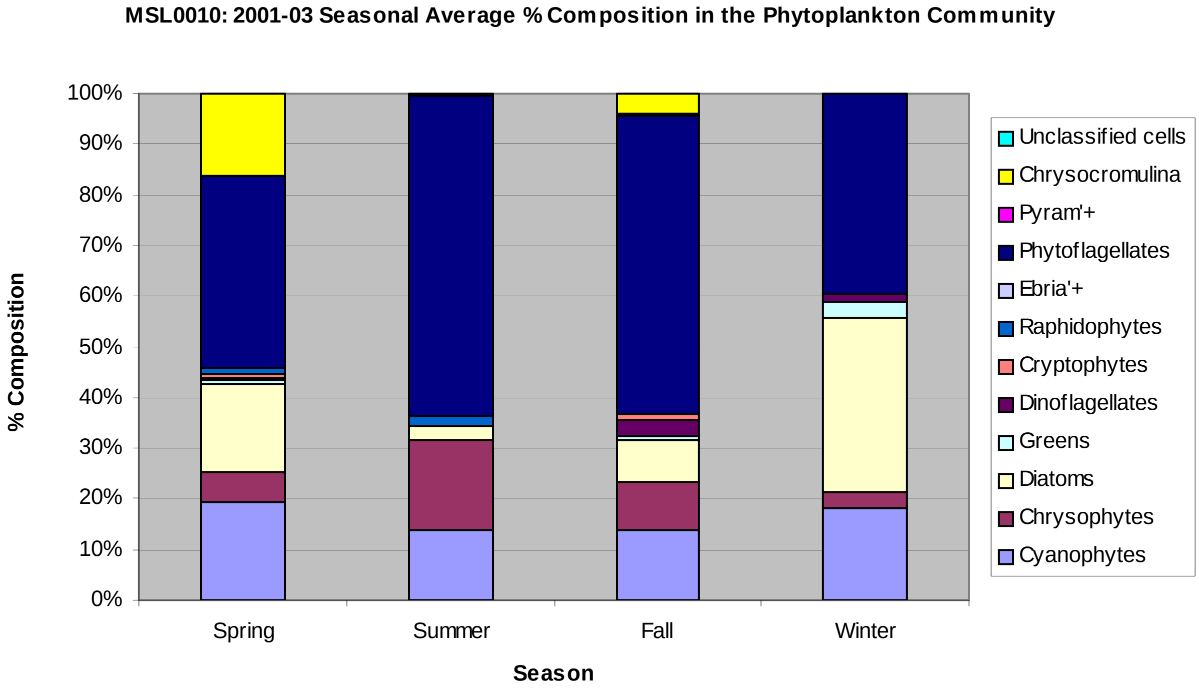

Figure 8.1.12. Phytoplankton community composition at station MSL0010 (Newport Bay).

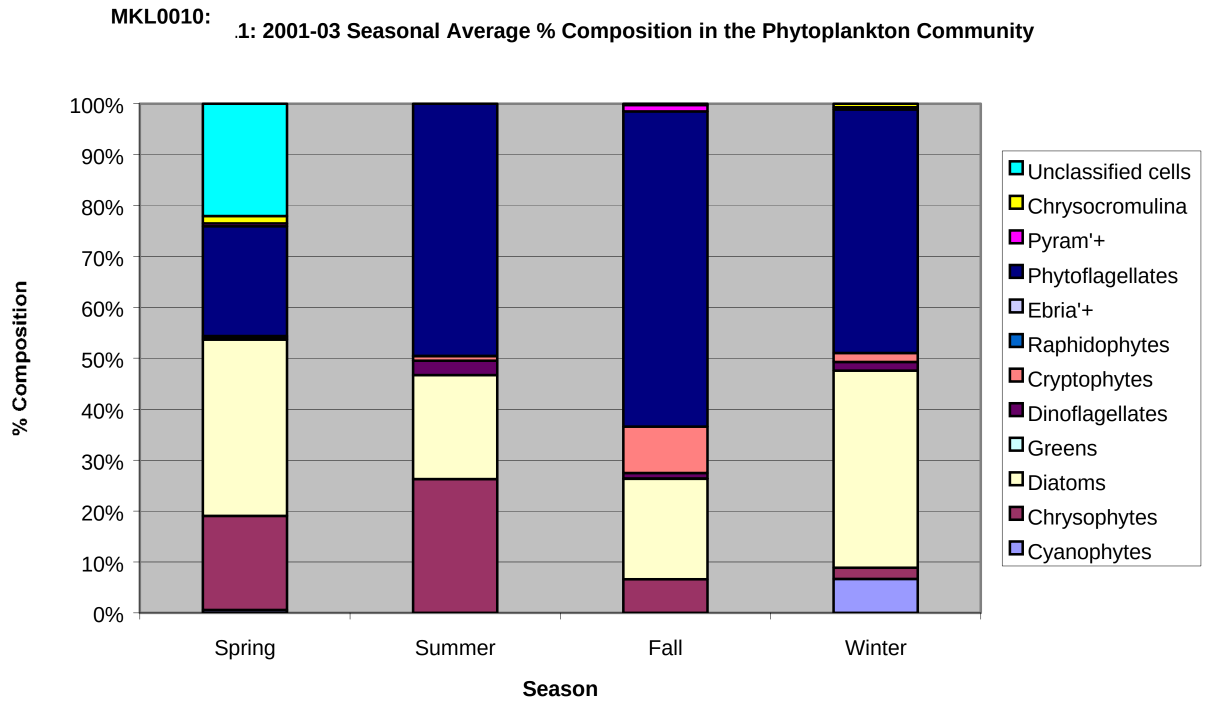

Figure 8.1.13. Phytoplankton community composition at station MKL0010 (Newport Bay).

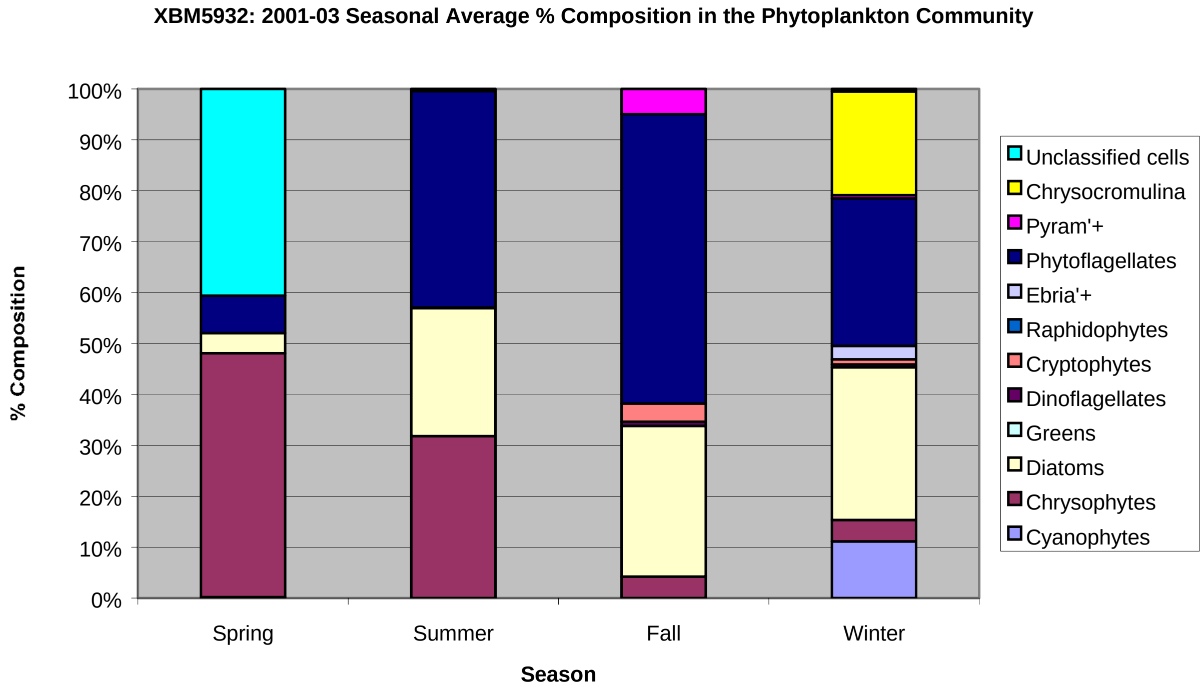

Figure 8.1.14. Phytoplankton community composition at station XBM5932 (Chincoteague Bay).

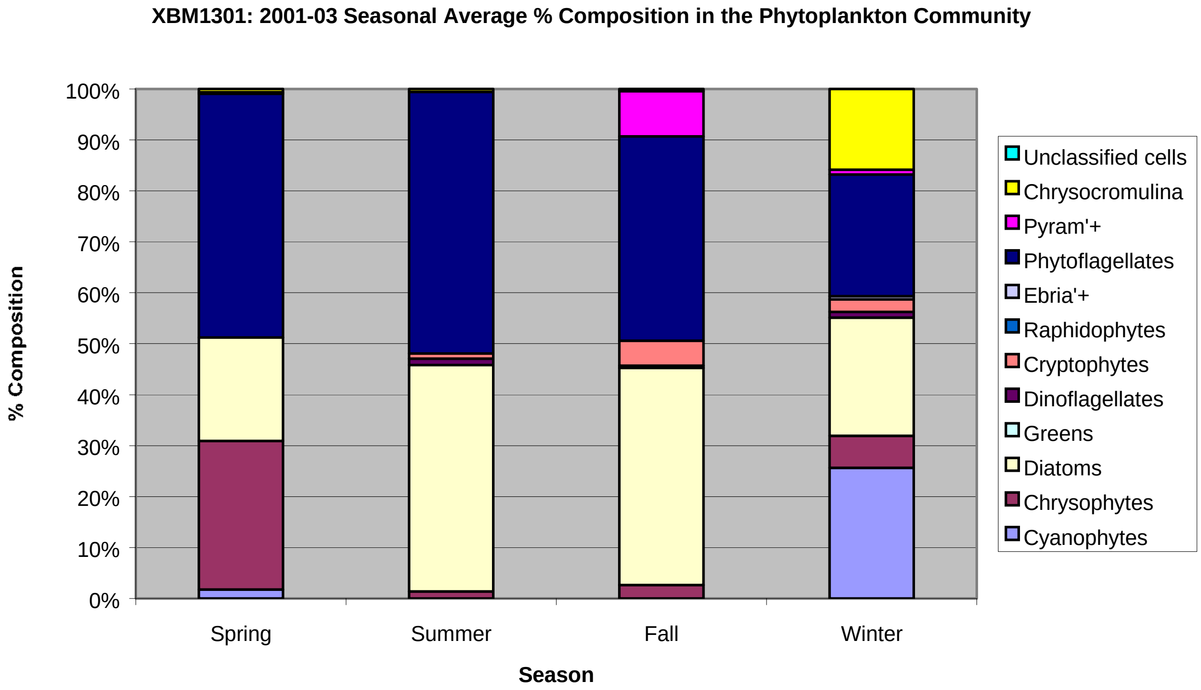

Figure 8.1.15. Phytoplankton community composition at station XBM1301 (Chincoteague Bay).

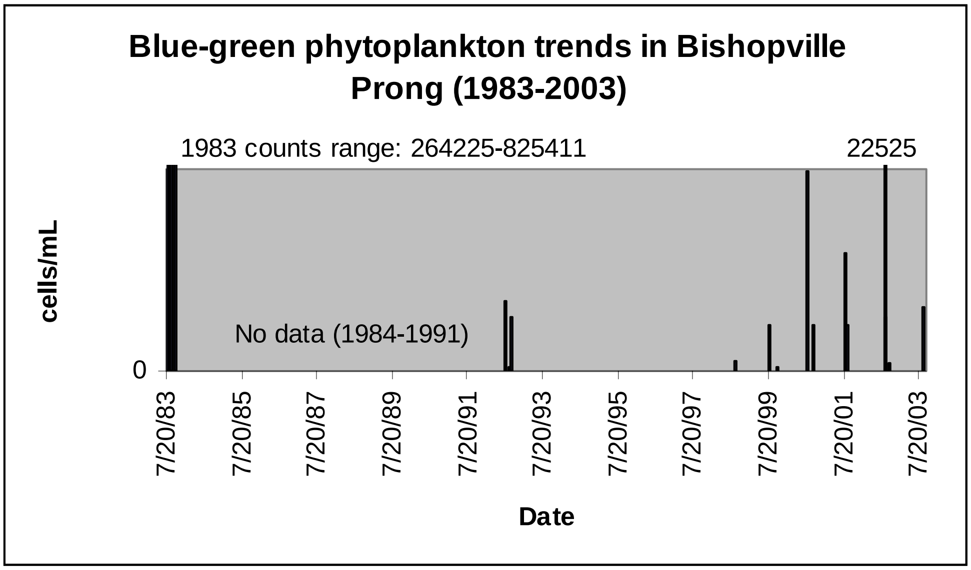

Figure 8.1.16: Trends in blue-green phytoplankton population (1983 and then 1992-2003) on Bishopville Prong (XDM4486). Counts exceeding 15000 cells/mL are shown next to corresponding bar.

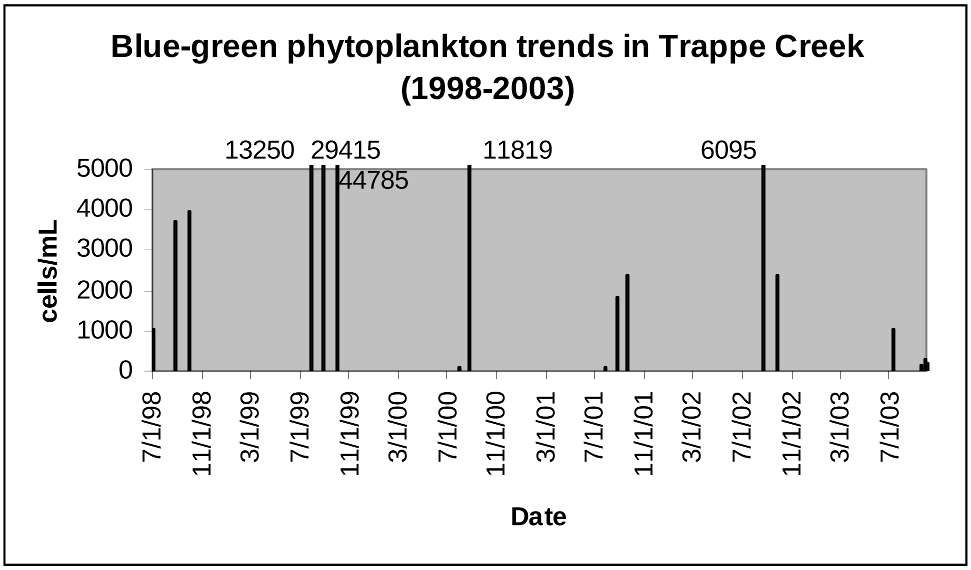

Figure 8.1.17: Trends in blue-green phytoplankton population (1998 – 2003) on Trappe Creek. Counts exceeding 5000 cells/mL are shown next to corresponding bar.

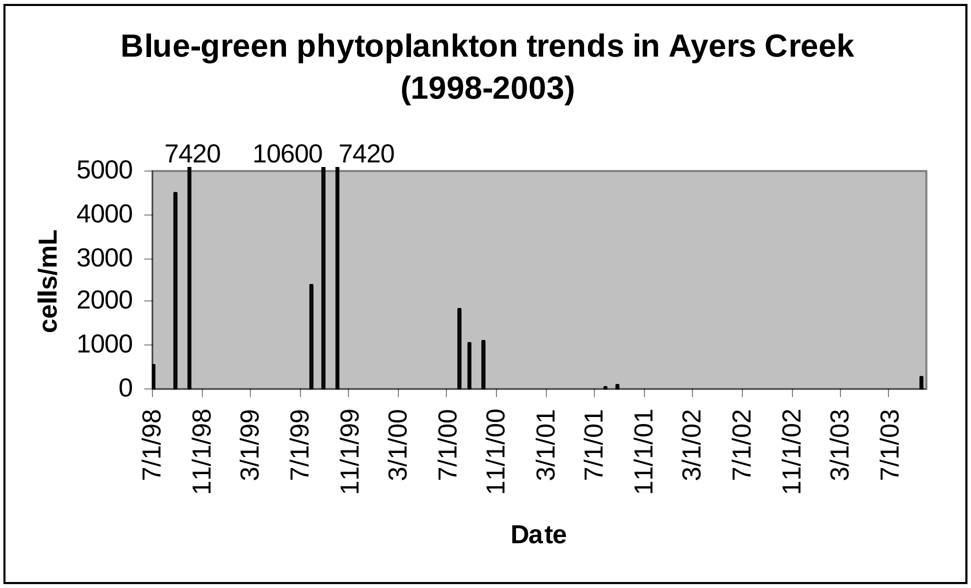

Figure 8.1.18: Trends in blue-green phytoplankton population (1998 – 2003) on Ayers Creek. Counts exceeding 5000 cells/mL are shown next to corresponding bar.

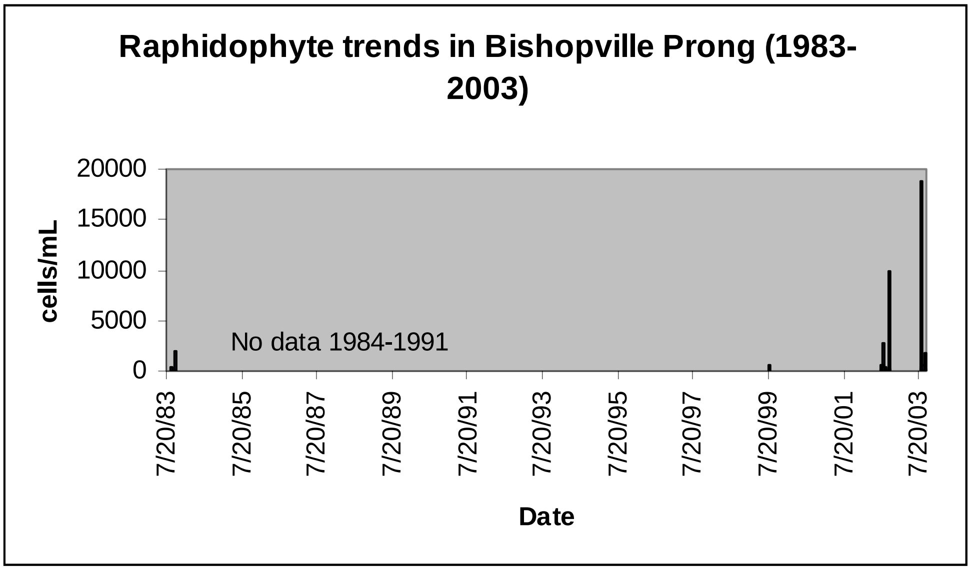

Figure 8.1.19: Trends in Raphidophyte population (1983 – 2003) on Bishopville Prong (XDM4486).

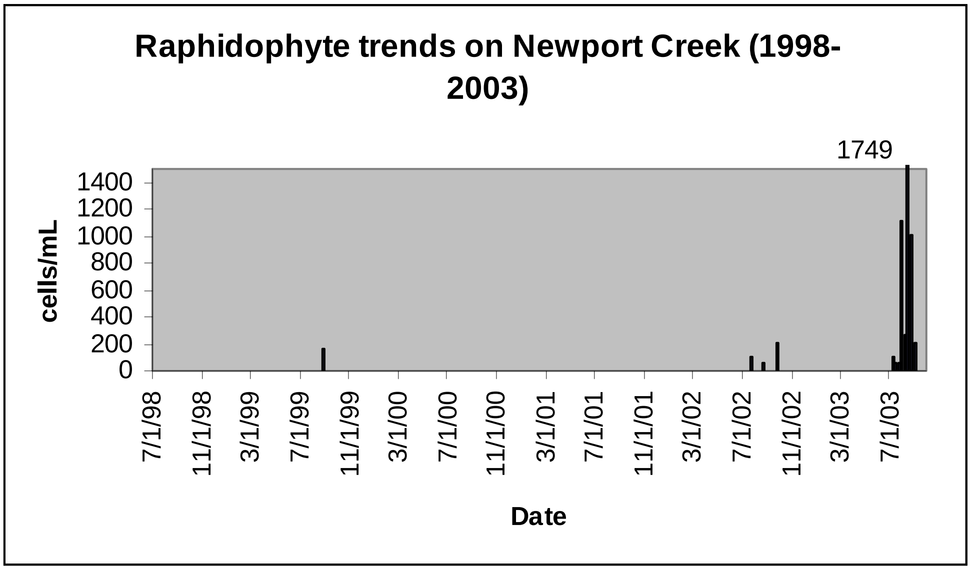

Figure 8.1.20: Trends in Raphidophyte population (1998 – 2003) on Newport Creek. Counts exceeding 1500 cells/mL are shown next to corresponding bar.

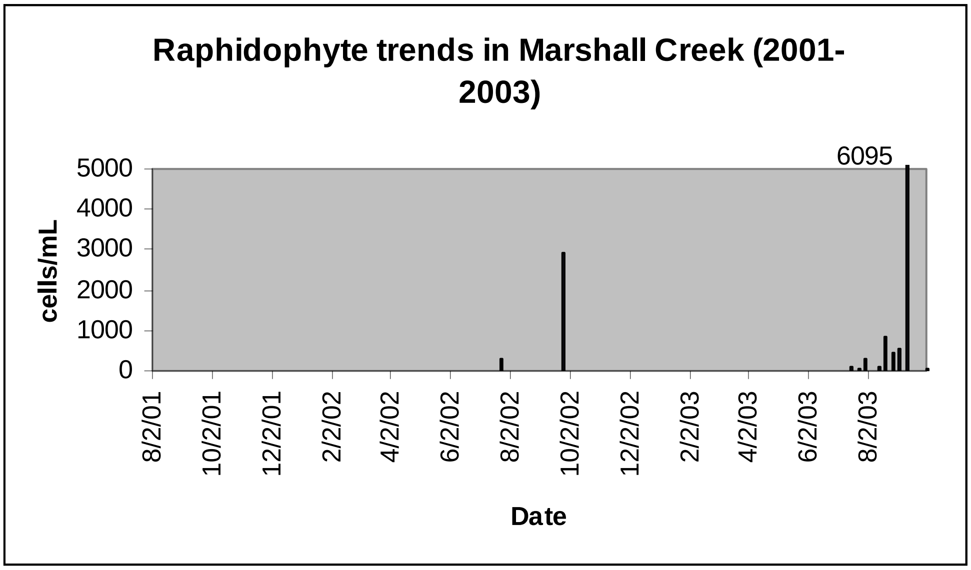

Figure 8.1.21: Trends in Raphidophyte population (2001 – 2003) on Marshall Creek. Counts exceeding 5000 cells/mL are shown next to corresponding bar.

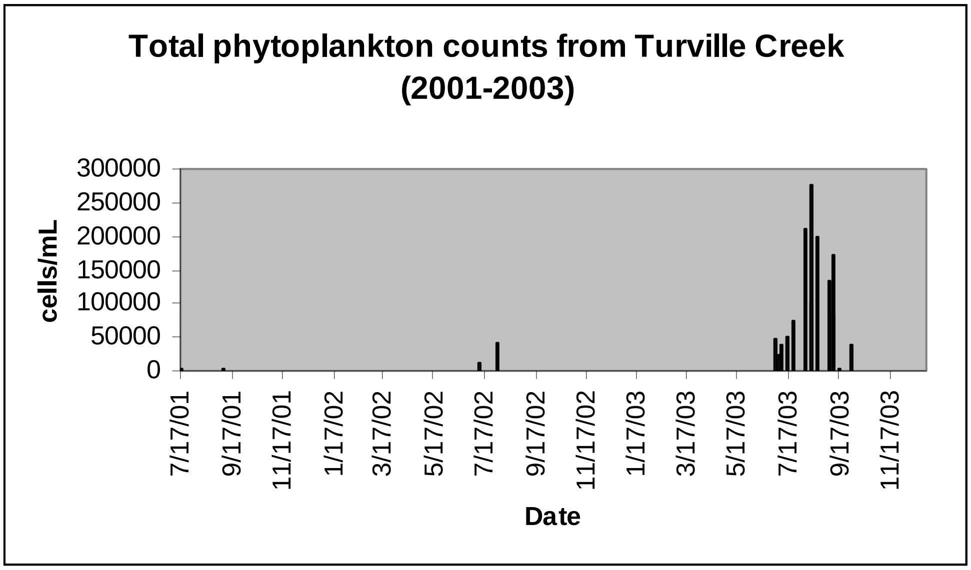

Figure 8.1.22: Trends in total phytoplankton population (2001 – 2003) on Turville Creek.

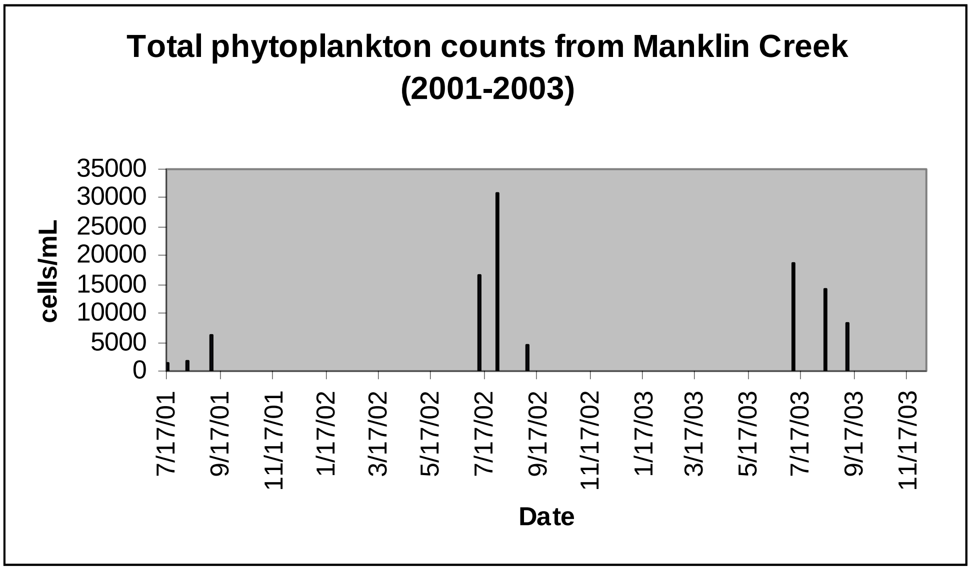

Figure 8.1.23: Trends in total phytoplankton population (1992 – 2003) on Manklin Creek.

Chapter 8.2

Status of finfish populations in the Maryland Coastal Bays

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Abstract

The Coastal Bays contain a diverse community of finfish populations. Many of the mid-Atlantic region's most valuable commercial finfish are composed of estuarine-dependent types like summer flounder (*Paralichthys dentatus*), bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), striped bass (*Morone saxatilis*) and others. These species depend on the Coastal Bays as a place to find food, and several species use the bays as a nursery. A forage fish index has been developed and adopted as a measure of food availability in the Bays. This index is based on the abundance of four species - bay anchovy (*Anchoa mitchelli*), menhaden (*Brevoortia tyrannus*), spot, and Atlantic silverside (*Menidia menidia*). These species represent the most common finfish forage in Maryland's Coastal Bays. Since 1972, the Maryland Department of Natural Resources (DNR) has monitored this resource through annual trawl and seine surveys. Despite annual fluctuations, the forage index from both trawl and seine surveys trended downward slowly since the mid-1980's.

Introduction

Finfish stocks in the Atlantic Coastal Bays of Maryland continue to support a diverse finfish population. These shallow waters are ideal nursery and forage habitat for over 140 species of finfish. Additionally, well over 120 species of epibenthic and benthic fauna have been identified, many of which serve as prime forage for juvenile and adult finfish of commercial and recreational value.

Much of the region's most valuable commercial catch is composed of estuarine-dependent species like summer flounder (*Paralichthys dentatus*), bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), spot (*Leiostomus xanthurus*), croaker (*Micropogonias undulatus*), striped bass (*Morone saxatilis*) and others. In 2002, commercial landings in Ocean City comprised 12.1 million pounds valued at 8.1 million dollars. Sportfishing is also an important economic component in Maryland. In 2003, over 700,000 people fished seven million days in Maryland waters with recreational saltwater fishing being one of the top outdoor activities. Recreational fishermen seek summer flounder, bluefish, weakfish, Atlantic croaker, and striped bass, and participate in as many as 13 annual tournaments open to Coastal Bays and near-shore Atlantic fishermen.

Many species in the Coastal Bays are dependent on coast-wide trends. Hence, fish populations in the Coastal Bays can be impacted by overfishing elsewhere as well as from degradation by eutrophication in other estuaries along the east coast. Recent management efforts lead to the development of fishery management plans for blue crabs and hard clams in the Coastal Bays.

Analyses

Forage fish index

Forage for both commercially and recreationally valuable finfish is considered a necessity for survival of juvenile finfish that use the Coastal Bays. Being sensitive to maintenance of a quality habitat, these species can be one of the first indicators of a stressed environment. A **forage fish index** was developed and adopted as a measure of food availability in the bays. This index, comprised of four species - bay anchovy, menhaden, spot, and Atlantic silverside - represents the most commonly sought finfish forage in Maryland's Coastal Bays. It is assembled from the results of an annual trawl and seine survey carried out by DNR Fisheries personnel at 20 monthly trawl sites (April through October) and at 19 seine sites each in the months of June and September (Figure 8.2.1). This survey has been maintained continuously for 31 years.

Summer flounder

The Maryland Coastal Bays are important habitat for summer flounder as they use the area to feed and grow. Newly hatched summer flounder enter the estuary in April at a very small size after being transported to the Ocean City inlet from the continental shelf where they were spawned in the winter. As they settle out in the Coastal Bays they begin to feed first on microscopic organisms, progressing to small shrimps, crabs, and fish as they increase in size. Larger summer flounder also return to the Coastal Bays each summer to take advantage of the rich food available in the estuary.

Summer flounder are a very popular target for recreational fishermen in the Coastal Bays. They are present and targeted by fishermen from April through October. Recent recreational harvests in Maryland fluctuated between 40,000 to 135,000 animals with a total weight of 100,000 to 250,000 pounds. The recreational fishery is important to the local economy benefiting bait stores, boat liveries, restaurants, and hotels. An annual hard quota has controlled commercial landings for summer flounder since 1993 (226,570 pounds in Maryland) that the industry cannot exceed.

Fish Indicator: Trend in forage fish index
***DRAFT* indicator:** Flounder trends

Results

Status and trends of forage fish index

Since the mid-1980's, forage indices for both the trawl and seine surveys continued a slow downward trend (Figure 8.2.2 and 8.2.3). Current status is gradually declining. This trend is based on a bay-wide data compilation, so regionalizing effects to the various segments of the Coastal Bays could cause a loss of accuracy.

The top ten species, including invertebrates, collected in 2003 from both the trawl and seine surveys are shown in Table 8.2.1. This demonstrates the diversity of species found in the Coastal Bays. A full list of species found in the Coastal Bays since study inception is found in Appendix A of this chapter.

Detailed analysis of forage fish index trends and species observed during annual surveys are found in Casey et al. 2002.

Status and trends in summer flounder abundance

The Maryland Coastal Bays is used as summer habitat for both juvenile and adult summer flounder. The Atlantic States Marine Fisheries Commission has managed summer flounder since the Atlantic Coastal Population collapse of the species from overfishing in 1989. Maryland, along with other Atlantic States, cooperates in the management of the species through commercial quotas and recreational harvest limits. Since interstate management of the species began, the stock recovered to a level no longer considered to be overfished. However, target levels of abundance have not been reached. Figure 8.2.4 shows the trend in summer flounder in the Coastal Bays. A detailed analysis of summer flounder trends, as well as trends for other commercial species, is found in Casey et al. 2002.

Summary

These shallow bays provide habitat for over 140 tidal finfish species and over 120 species of epibenthic and benthic invertebrates (Casey et al. 2002). Overall, the top ten most abundant species have not changed substantially from 1972 to present (Casey et al. 2002).

Despite annual fluctuations, the forage fish index from both trawl and seine surveys shows a slow downward trend since the mid-1980's. This decline is dominated by the decreased abundance of spot since then, following a coast-wide decline. However, the other species in the index have also been slowly declining. The stock of summer flounder has recently recovered and is no longer considered overfished, although target levels of abundance have not been reached.

Additional measures of fish community health are in the process of being developed by the Maryland Coastal Bays Program (Index of Biotic Integrity, principle components analysis, and indicator species).

References

Casey, J.F., S.B. Doctor, and A.E. Wesche. 2002. Investigation of Maryland's Atlantic Ocean and Coastal Bay Finfish Stocks. Report for Federal Aid Project No. F-50-R. Maryland Department of Natural Resources, Stevensville, MD.

Table 8.2.1**:** Most abundant species found during 2003 seine and trawl surveys conducted by the Maryland DNR Fisheries Service. OC – Ocean City. * - Invertebrate.

Rank abundance	**Trawl sites above OC inlet**	**Trawl sites below OC inlet**	**Seine sites above OC inlet**	**Seine sites below OC inlet**
1	Silver perch, *Bairdiella chrysoura*	Lady crab*, *Ovalipes ocellatus*	Atlantic needlefish, *Strongylura marina*	Blue crab*, *Callinectes sapidus*
2	Mottled dog whelk*, *Nassarius vibex*	Silver perch, *Bairdiella chrysoura*	Summer flounder, *Paralichthys dentatus*	White mullet, *Mugil curema*
3	Summer flounder, *Paralichthys dentatus*	Spot, *Leiostomus xanthurus*	Silver perch, *Bairdiella chrysoura*	Winter flounder, *Pleuronectes americanus*
4	Grass shrimp*, *Palaemonetes* spp.	Northern sea robin, *Prionotus carolinus*	Spot, *Leiostomus xanthurus*	Bay anchovy, *Anchoa mitchelli*
5	Atlantic croaker, *Micropogonias undulatus*	Grass shrimp*, *Palaemonetes* spp.	Winter flounder, *Pleuronectes americanus*	Sand shrimp*, *Crangon septemspinosa*
6	Sea grape (tunicate)*, *Mogula manhattanensis*	Summer flounder, *Paralichthys dentatus*	Grass shrimp*, *Palaemonetes* spp.	Atlantic menhaden, *Brevoortia tyrannus*
7	Blue crab*, *Callinectes sapidus*	Weakfish, *Cynoscion regalis*	Bay anchovy, *Anchoa mitchelli*	Silver perch, *Bairdiella chrysoura*
8	Weakfish, *Cynoscion regalis*	Bay anchovy, *Anchoa mitchelli*	Blue crab*, *Callinectes sapidus*	Blue mussel, *Mytilus edulis*
9	Sand shrimp*, *Crangon septemspinosa*	Blue crab*, *Callinectes sapidus*	Atlantic silverside, *Menidia menidia*	Atlantic silverside, *Menidia menidia*
10	Bay anchovy, *Anchoa mitchelli*	Sand shrimp*, *Crangon septemspinosa*	Atlantic menhaden, *Brevoortia tyrannus*	Grass shrimp*, *Palaemonetes* spp.

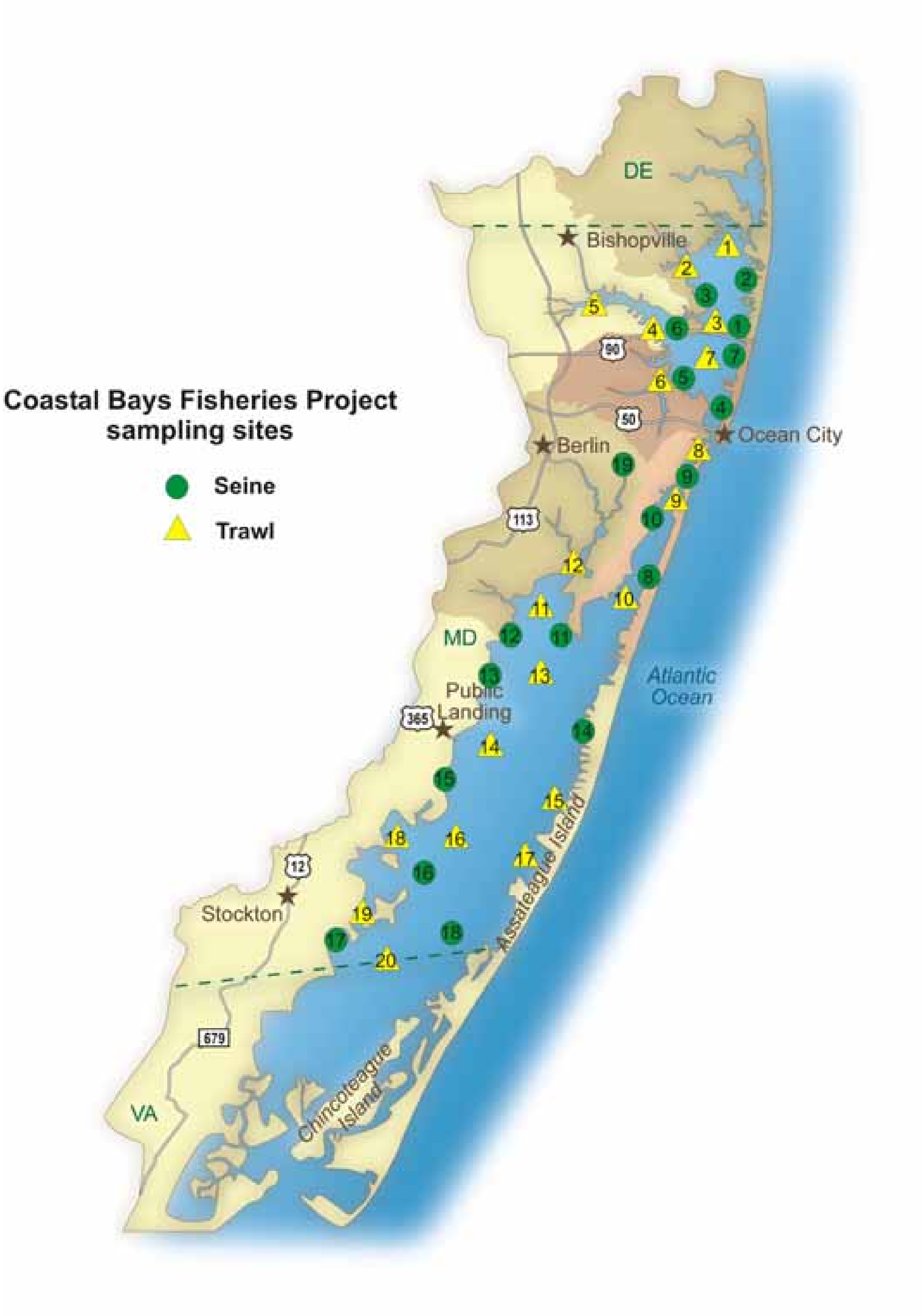

Figure 8.2.1: Map showing locations of Coastal Bays Fisheries Project trawl and seine sampling sites.

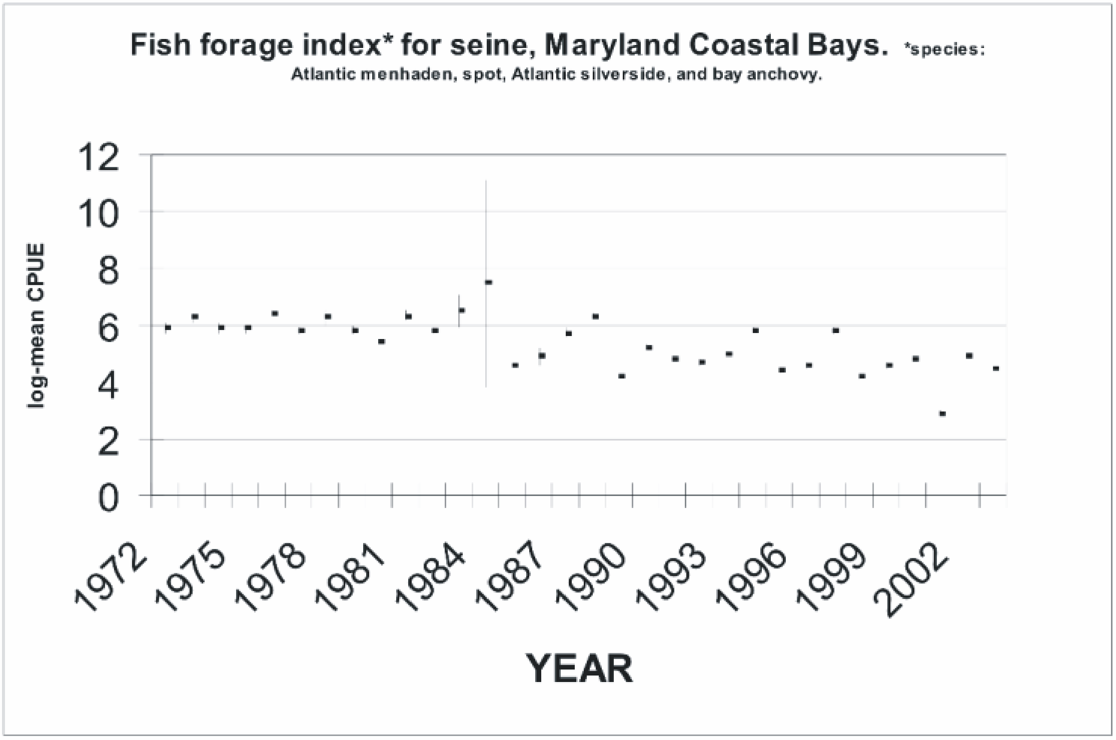

Figure 8.2.2: Forage fish index for trawl samples since 1973. All values are in mean catch per unit effort based on the number of trawls completed each year in the Coastal Bays. Error bars represent the standard error of the log-transformed means.

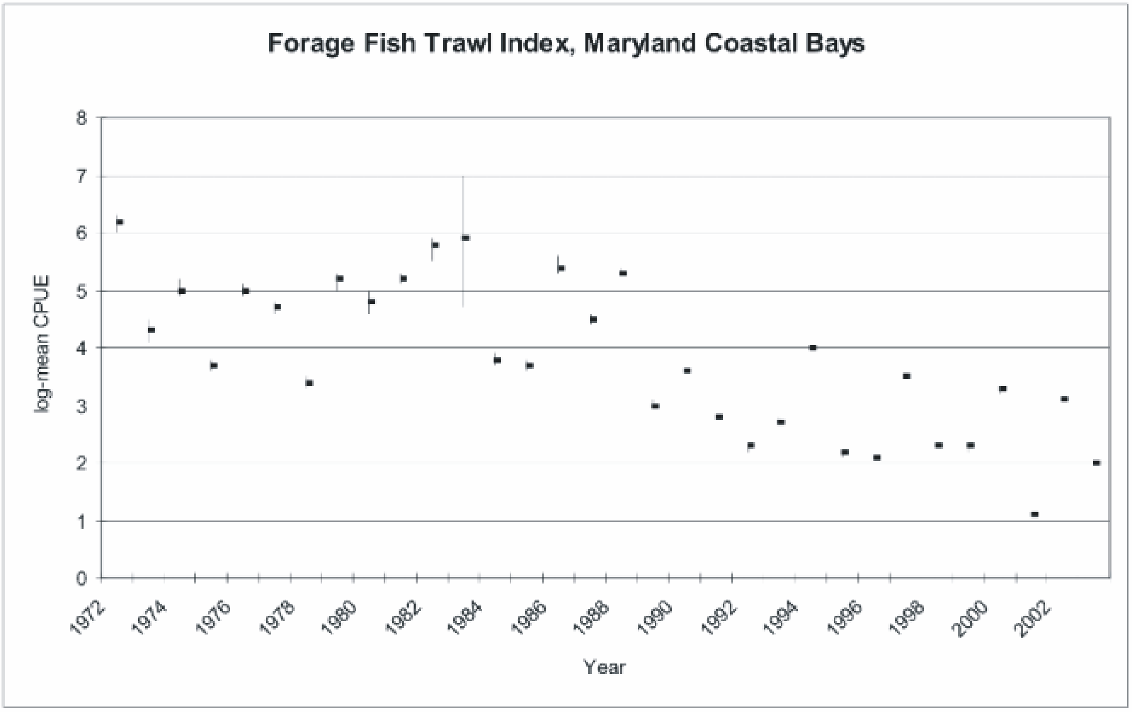

Figure 8.2.3: Forage fish index for seine samples since 1973. All values are in mean catch per unit effort based on the number of seine pulls completed each year in the Coastal Bays. Error bars represent the standard error of the log-transformed means.

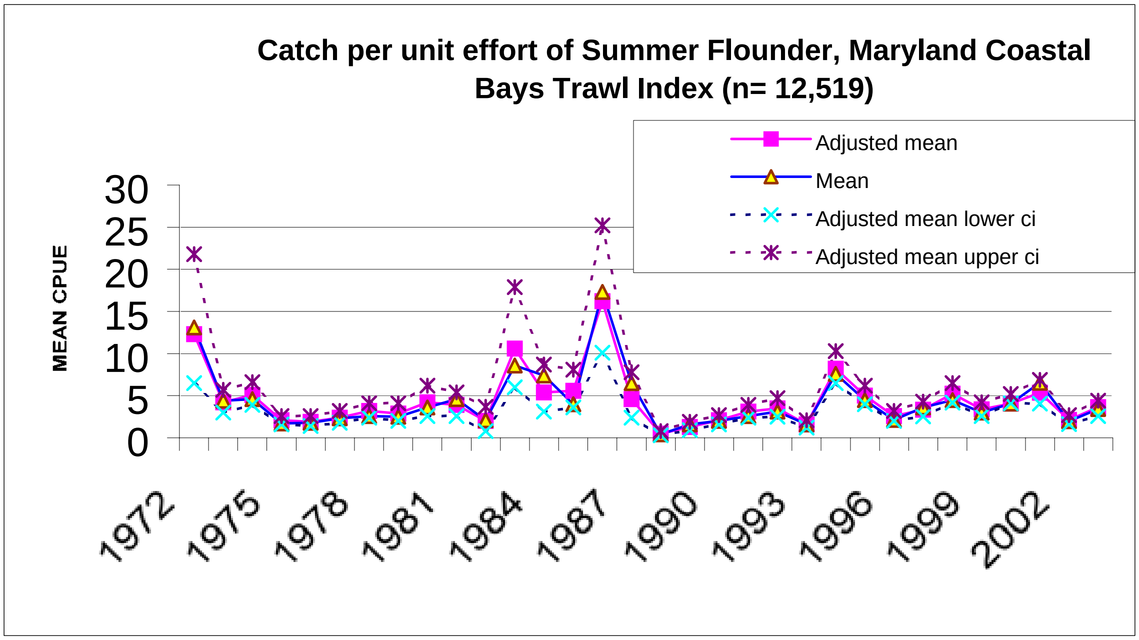

Figure 8.2.4: Annual mean summer flounder catch per unit effort during the DNR Coastal Bays trawl survey. Dashed lines indicate 95% confidence limits. The adjusted mean was calculated by multiplying the geometric mean by he sum of the time series arithmetic mean divided by the sum of the geometric means (Casey et al. 2002).

Chapter 8.3

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 51 reported fish kills and 49 confirmed or probable fish kills in the Coastal Bays Region since 1984. Collectively they represent approximately 3.3 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 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, multi-agency 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 20 years. This report is a summary of events reported in the Coastal Bays region from 1984-2003.

There have been 51 reported fish kills and 49 confirmed or probable fish kills in the Coastal Bays Region since 1984. Collectively they represent approximately 3,300,000 mortalities. During the same period, there were 1,259 fish kill reports, involving approximately 35,000,000 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

Fish kills in the Coastal Bays were generally confined to dead-end canals. Canals are confined spaces with characteristically low flushing where frequent algae 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 8.3.1). Fourteen of the eighteen reports involving canals were attributed to low dissolved oxygen. The vast majority (97.9%) of mortalities also occurred within canals (Figure 8.3.2). 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 16 reports from creeks and rivers, all but one occurred in smaller creeks near tidal headwaters. The most common cause of these events was low dissolved oxygen (five of eight events where cause was determined).

Trends of fish kills

Temporal Patterns

The majority of fish kills occurred in the summer months in the Coastal Bays Region as they did throughout the state (Table 8.3.1). 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 Region in the months of January and February. This is largely due to the fact that schools of five to eight inch striped mullet (*Mugil cephalus*) were found dead and dying of cold stress in each of the last four winters throughout the area. While most fisheries accounts of the Middle Atlantic Region suggest that the species leaves the area in fall and moves south, apparently some attempted to over winter in the area.

Table 8.3.1- Fish Kill Reports by Month: 1984-2003.

Month	# Reported Kills Statewide	# Reported Kills Coastal Bays
January	57	4
February	53	3
March	94	0
April	176	2
May	443	3
June	445	7
July	405	9
August	332	18
September	213	2
October	58	1
November	24	2
December	15	0

The number of fish kills reported per year varied 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 does not appear to be changing statewide (Table 8.3.2). However, the number of fish kills reported per year in the Coastal Bays Region increased with time. The average number of kills reported in the late 1980's through the 1990's was 1.5 per year. That number increased to seven per year over the last four years.

Either increased environmental stress or increased public awareness resulting from renewed interest in environmental initiatives in the Coastal Bays area may explain the increase in fish kill reports.

Table 8.3.2- Fish Kill Reports per Year

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	127	5
TOTAL	**2327**	**51**

Cause

Approximately 12% of all fish kills statewide were pollution related. Pollution induced fish kills were 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.

Table 8.3.3- Fish Kills by Cause: 1984-2003

Cause of Fish Kills	**Statewide Cases (% where cause is known)**	**Coastal Bays Cases (% where cause is known)**
Low Dissolved Oxygen	**751 (45.8 %)**	**24 (66.7%)**
General	270	4
Algal bloom	185	6
Entrapment	113	12
Intrusion/Inversion	67	1
Stranding	49	1
BOD	15	0
Winter Kill	52	0
Unknown	**595 (26.6%)**	**13 (26.5%)**
Discards	**301 (18.4 %)**	**4 (11.1 %)**
Thermal Stress	**37 (2.3 %)**	**5 (13.9 %)**
Disease	**196 (12.0 %)**	**0**
Seasonal/Spawning Stress	**103 (6.3 %)**	**0**
Pond Management	**42 (2.6 %)**	**1 (2.8 %)**
Misc. Natural	**15 (0.9 %)**	**0**
Storm Winds	**1 (0.1 %)**	**1 (2.8 %)**
Pollution	**188 (11.5 %)**	**1 (2.8%)**
Toxic Algae	**4 (0.2 %)**	**0**
TOTAL KILLS	**2233**	**49**

Statewide, approximately half of all tidal fish kills where the cause was known were attributable to low dissolved oxygen (Table 8.3.3). 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 dissolved oxygen (DO) that could be attributed to nightly DO sags resulting from algal blooms, inversions, or intrusions of deep anoxic water onto shorelines. Low dissolved oxygen was implicated in two thirds of all fish kills where the cause was known in the Coastal Bays Region. While entrapment in man-made structures accounted for 15 percent of all low DO kills statewide, this accounted for half of all low DO kills in the Coastal Bays.

Mortalities

Of the estimated 37,500,000 fish mortalities statewide since 1984, 93 percent died in low DO events. Of the 3,302,300 fish mortalities in the Coastal Bays Region, approximately 98 percent died in low DO events (Table 8.3.4). The species most affected were schooling species, such as Atlantic silversides (*Menidia menidia*), Atlantic menhaden (*Brevoortia tyrannus*), and striped mullet (Table 8.3.5).

Table 8.3.4: Fish mortalities by cause: 1984-2003.

Cause of Fish Kills	**Coastal Bays Mortalities**	**Statewide Mortalities**
Low Dissolved Oxygen	**3,231,858 (97.9%)**	**34,699,050 (92.6 %)**
General	15,277	3,895,600
Algal bloom	3,862	13,062,500
Entrapment	3,200,719	3,563,700
Intrusion/Inversion	10,000	317,100
Stranding	2,000	13,492,100
BOD	0	317,550
Winter Kill	0	50,500
Unknown	**34,350 (1.0 %)**	**698,225 (1.9 %)**
Discards	**30,712 (0.9 %)**	**132,200 (0.4 %)**
Thermal Stress	**4,900 (0.1 %)**	**38,700 (0.1 %)**
Disease	**0**	**850,900 (2.3 %)**
Seasonal/Spawning Stress	**0**	**20,200 (0.0 %)**
Pond Management	**300**	**34,100 (0.1 %)**
Misc. Natural	**0**	**5,800 (0.0 %)**
Storm Winds	**25**	**25 (0.0 %)**
Pollution	**150**	**955,700 (2.6 %)**
Toxic Algae	**0**	**17,400 (0.0 %)**
TOTAL KILLS	**3,302,295**	**37,452,300**

Table 8.3.5: Mortalities of fish by species in the Coastal Bays region: 1984-2003.

Fish species	**Number killed in Coastal Bays**
atlantic silversides, *Menidia menidia*	3,000,000
atlantic menhaden, *Brevoortia tyrannus*	290,675
striped mullet, *Mugil cephalus*	4,950
bluegill sunfish, *Lepomis macrochirus*	1,815
golden shiner, *Notemigonus crysoleucas*	1,375
minnow species	636
black sea bass, *Centropristis straita*	500
18 remaining species	2,344

Summary

The only pollution case in the Coastal Bays Region 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 MDE biologists could accurately assess the damage. At least 150 fish died. No acute effects were visible below the pond in Bishopville Prong.

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. **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. DO at the time of investigation was 0.77 mg/l.
3. **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.
4. **July 8,1993** in the Atlantic Ocean off Assateague Island. Approximately 30,000 adult Atlantic menhaden were discarded by commercial fishing operations.
5. **June 7, 2002** in a canal off Isle of Wight Bay in West Ocean City. Approximately 15,000 Atlantic menhaden died due to low DO.
6. **September 12, 1985** in a canal off the Saint Martin's River in Ocean Pines. Approximately 10,000 Atlantic menhaden died due to a storm induced anoxic inversion.
7. **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 collected 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).

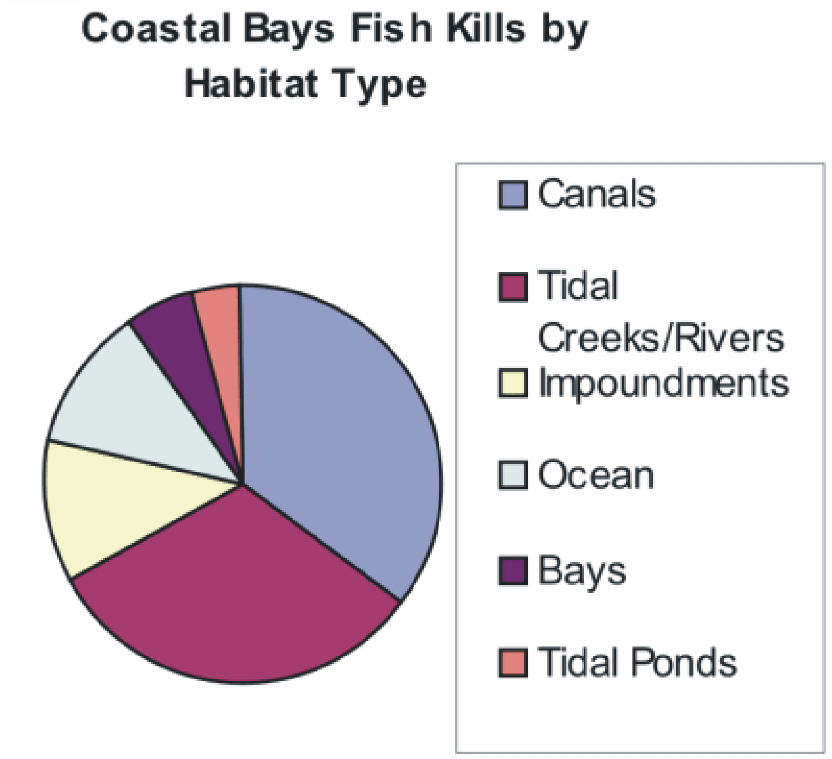

Figure 8.3.1. Number of fish kills per habitat type, 1984-2003.

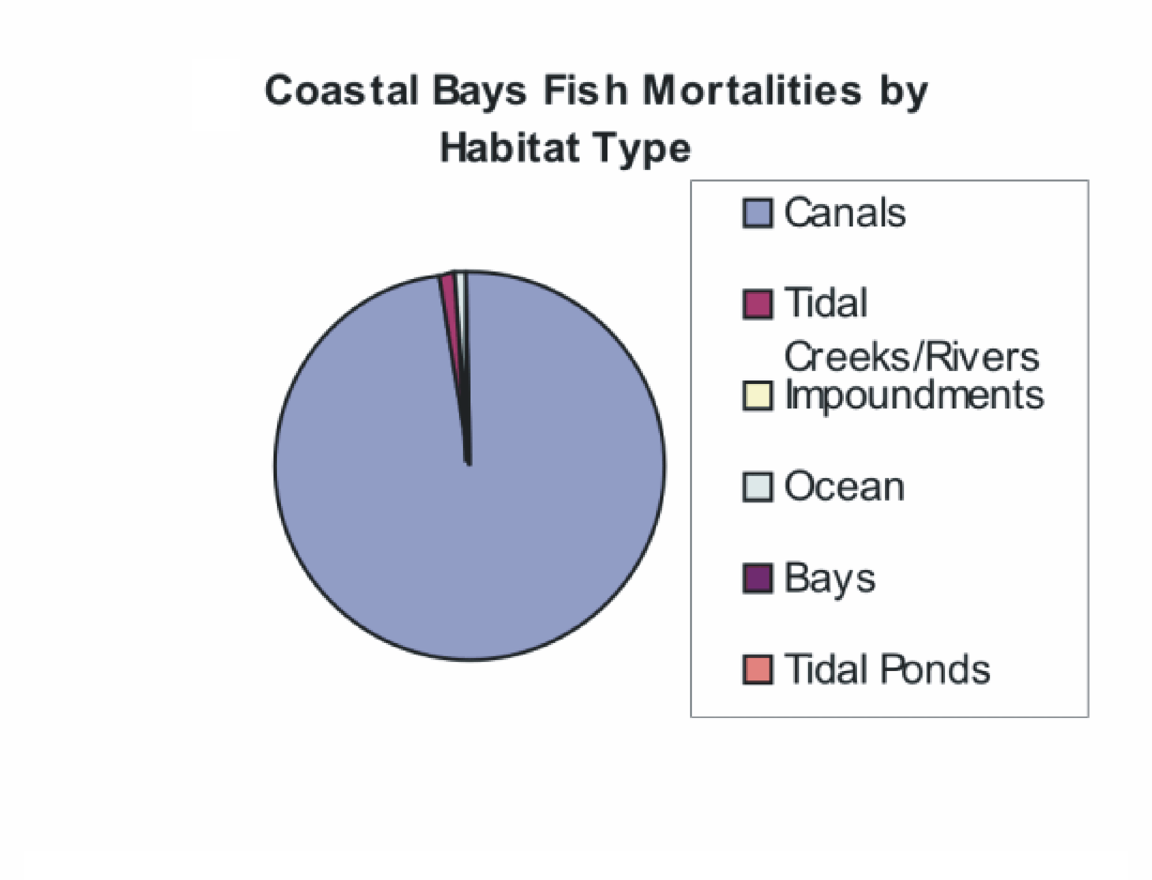

Figure 8.3.2. Numbers of fish killed during fish kill events per habitat type, 1984-2003.

Chapter 8.4

Status of shellfish populations in the Maryland Coastal Bays

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Abstract

In 1993 the Maryland Department of Natural Resources (MDNR) 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. Between 1993 and 1996, over 50,000 live individuals comprising 63 molluscan species and an additional 10 species represented only by dead specimens were collected. 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, presently there are no oyster (*Crassostrea virginica*) populations inhabiting the subtidal relic shell bars of the Coastal Bays. Hard clam (*Mercenaria mercenaria*) densities, which historically have been lower than in other regions of the East Coast, are about 25% of estimates made 35 to 50 years ago, but have been relatively stable for the past 10 years. Bay scallops (*Argopecten irradians*) have recently returned and occur in most of the Coastal Bays, albeit in very low numbers. In the absence of long-term data sets, the high degree of spatial and temporal variability due to physical and biological factors creates difficulty in drawing strong conclusions about trends in molluscan population and community dynamics. Consequently, MDNR continues to track the population status of select species.

A. General 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. 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. Potential threats to molluscs include invasive green crabs, QPX disease and brown tide.

Mollusc Community Data Sets

Assateague Ecological Studies, 1969-1971. Data are as number per m^2 and in tables, sample sites are given on maps.

DNR surveys, 1980-1981. Most samples were from Isle of Wight Bay. Data are in tables (number per unit area) with map of sampling sites.

Coastal Bays Joint Assessment, EPA EMAP Surveys, 1993. Data are presented in tables. Sites are depicted on maps. Latitude/longitude sample site information is available from EPA.

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, 2000-2003.

National Park Service, 1994-1996. Box core and trawl samples in Chincoteague and Sinepuxent Bays. Includes seasonal data. Data available from NPS.

DNR Molluscan Inventory, 1993-1996. 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 (MCBP CCMP Objective FW 1.3)

General Mollusc Indicators:

1. Density (# live /unit area)
2. Geographic Distribution (lat/long; bay or tributary; sub-bay or region)

Data Analyses

Between October 1993 and September 1996, the DNR Shellfish Program conducted a comprehensive study 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. Samples were collected using a Ponar grab sampler that sampled 0.05 m^2 of the bottom. The samples were then sieved through a 1 mm mesh screen and preserved. For each sample, all molluscs were identified and enumerated, and population size class structures were developed for each identified species. For an account of molluscan sampling, see Tarnowski 1997b. During the three- 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 quadrate.

Results: General Mollusc Status

Over 50,000 live individuals comprising 63 mollusc species were collected; an additional 10 species were represented by dead specimens only (for a full 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 northern 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 (diversity), abundance, size structure, and habitat characterization. Among the findings were 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 open 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 (Virginian and Carolinian), 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. Intertidal structures can provide additional scarce, hard substrate as a supplement, but not substitute, for existing natural intertidal shoreline.

General Mollusc Summary

Among the findings characterizing the molluscan shellfish communities of the Coastal Bays was high species diversity, with significantly lower abundances in coastal tributaries than open bays. Coastal Bays molluscan communities (the types of species and number of animals) varied considerably from location to location and over time showing high seasonal and annual variability. Community structure was strongly influenced by habitat conditions, including the type of sediment, biogenic structures (such as worm tubes, seagrasses, and shell cover), interaction with other biological communities, and natural catastrophic events. This high degree of variability makes it difficult to draw strong conclusions about trends in these communities.

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 more 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 subsequently developed throughout the bays. Since the 1960's, 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.

Hard Clam Data Sets

Md. Department of Research and Education. 1952-1953. System-wide hard clam study includes density, distribution, size structure, and habitat.

University of Maryland Assateague Ecological Studies. 1969-1970. This study uses the same data classes as above, with emphasis on eastern Chincoteague Bay. No samples were taken north of the Ocean City Inlet.

Maryland Department of Chesapeake Bay Affairs; MDNR. 1968-1971. Surveys of commercial hard clam areas were conducted.

Maryland Conservation Department; MD Bureau of Natural Resources; MD Department of Chesapeake Bay Affairs. 1928-1969. Annual Reports. Annual landings and licensing data as well as occasional anecdotal information.

DNR Shellfish Program. 1993-present. These system-wide hard clam surveys includes density, distribution, size structure, habitat and other organisms. Bay scallops are included in this survey, in addition to limited surveys dedicated to this species.

Management Objective: Maintain optimum sustainable clam abundances (MCBP CCMP objective FW 1.3)

Hard Clam Indicators:

Primary
- 1. Clam Density (# live/unit area)
- 2. Geographic Distribution of clams (lat/lo; bay or tributary; sub-bay or region)

Secondary
- 1. Size-Frequency Distribution of clams (% frequency)

Tertiary
- 1. Mortality
    - a) Natural (boxes*/unit area)
    - b) Harvest (commercial landing records)
- 2. Disease

* Boxes refer to articulated, empty shells and are indicative of recently dead clams.

Data Analyses

Hard clams have been sampled in Chincoteague Bay since 1993 and throughout the Coastal Bays almost annually from 1994 using a commercial hydraulic escalator dredge. The dredge was towed through a 76.2 m course at each site, effectively sampling 58.1 m^2. 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 8.4.1. Summary of DNR Hard Clam Surveys (1993/94-2003) and 1953 clam densities.

Nine Year Averages (1994-2003)						1953
	Total n	Length (mm)	%< 51 mm	% Dead	Live/m^2	Live/m^2
Chincoteague Bay[1]	952	74.6	14.2	5.3	0.27	1.30
Newport Bay	113	78.6	6.3	19.3	0.14	0.40
Sinepuxent Bay	167	71.4	21.0	3.4	0.32	1.04
Isle of Wight Bay	144	69.6	23.9	2.0	0.28	1.19
Assawoman Bay	120	73.1	15.8	4.2	0.16	1.00
St. Martin River[2]	40	85.2	0.0	18.6	0.04	0.14

[1] (1993-2003)

[2] (1996 – 1997)

Table 8.4.2. Annual rankings of Coastal Bays hard clam densities arranged from highest (top) to lowest (bottom). Average is for the years 1994 to 2003.

1953	1994	1996	1997	2000	2001	2002	2003	9 Yr. Avg.
Chin	Sin	Sin	Sin	Chin	Sin	IoW	IoW	Sin
IoW	Chin	Chin	IoW	Sin	Chin	Sin	Sin	IoW
Sin	IoW	Iow	Chin	IoW	Iow	Chin	Chin	Chin
Assa	Assa	Assa	New	Assa	Assa	Assa	Assa	Assa
New	New	New	Assa	New	New	New	New	New
StM		StM	StM					StM

Chincoteague Bay

a) 2003 Status

A total of 102 samples were taken employing a commercial clamming vessel equipped with a hydraulic escalator dredge (Figure 8.4.1). Average density was 0.21 clams/m^2, ranking Chincoteague Bay third among the five bays. Clams were more abundant on the east side of the bay, with highest concentrations in the southeastern quadrant (0.28 clams/m^2) (Figure 8.4.2). The lowest density was in the western bays complex (0.14 clams/m^2). The proportion of boxes in the population was 7.8%. The average length of the clams was 76.8 mm, with only 7.5% in the 31 - 50 mm size class, indicating relatively low recruitment.

b) 10-Year Trend

Since 1993, a total of 952 stations were sampled in Chincoteague Bay; surveys were not conducted in 1995 and 1999 (Table 8.4.1). Hard clam population densities remained relatively stable over the ten-year interval, with a modest increase observed in 2000 (Figure 8.4.3), when Chincoteague Bay ranked first among the Maryland Coastal Bays (Table 8.4.2). Densities over the past two years were somewhat lower than the ten-year average of 0.27 clams/m^2. Generally, clam densities were higher on the east side of the bay during this period. Boxes comprised 5.3% of the population. The ten-year average length of the clams was 74.6 mm, with 14.2% in the 31 - 50 mm size class. Recruitment was sporadic, with higher than average proportions of these small clams observed in 2000 and 2001, while five of the years were sub par (Figure 8.4.4).

c) 50-Year Benchmark

Four surveys were conducted intermittently over a 17-year interval prior to the DNR effort, but only the 1953 survey included the entire coastal system. Three of the studies were during the 1950's, when 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. In 1953 Chincoteague Bay had the highest clam densities of the Maryland Coastal Bays and was five times higher than the present 10-year average (Table 8.4.2). Mortality data were 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, and to 14.4% in 1969.

Newport Bay

a) 2003 Status

Hard clam densities averaged 0.12 clams/m^2 over 9 stations, the lowest density of the Coastal Bays (Figures 8.4.2 and 8.4.3). Boxes comprised 21.2% of the Newport Bay population. The average length of these clams was 78.2 mm, with 5.1% of the clams between 31 mm and 50 mm.

b) 9-Year Trend

Since 1994, a total of 113 samples were taken in Newport Bay; surveys were not conducted in 1995 and 1999 (Table 8.4.1). Clam densities were consistently the lowest of the five primary Coastal Bays, averaging 0.14 clams/m^2 (Figure 8.4.2). In contrast, box counts were the highest, averaging 19.3% of the population. The high percentage of boxes was probably due to the low level of clamming activity in this bay which allowed a greater rate of senescent mortality, with the boxes accumulating undisturbed by harvesting and protected in the soft sediment. This was further suggested by the high proportion of larger, older clams, with an average length of 78.6 mm. Recruitment was consistently poor, averaging 6.3% of the sampled population between 31 mm and 50 mm in length (Figure 8.4.4).

c) 50-Year Benchmark

Newport Bay always ranked lowest in clam densities among the Maryland Coastal Bays (Table 8.4.2). Between 1952 and 1969, densities dropped from 0.51 clams/m^2 to 0.08 clams/m^2, which was lower than the present population. Historic recruitment data were not available.

Sinepuxent Bay

a) 2003 Status

The average live clam density of 0.23 clams/m^2 was the lowest recorded in Sinepuxent Bay, even though this was second highest among the Maryland Coastal Bays this year; 23 samples were collected (Figure 8.4.2). Boxes accounted for 3.7% of the population. The average length was 73.8 mm, with 14.5% of the sampled population between 31 mm and 50 mm.

b) 9-Year Trend

Sinepuxent Bay placed first or second in live clam densities every year since 1994 and ranked first overall during this period (Table 8.4.2), averaging 0.32 clams/m^2 with 167 samples taken in total (Table 8.4.1). Surveys were not conducted in 1995 and 1999. The peak density of 0.47 clams/m^2 in 1996 was the highest recorded of the Coastal Bays during this period (Figure 8.4.3). The 9-year average observed natural mortality was 3.4%. This was one of the more consistent areas of recruitment, with 21.0% of the clams under 51 mm and the population averaging 71.4 mm in length. There was a series of relatively productive years in the mid to late 1990's, although the last three years have been somewhat below average (Figure 8.4.4).

c) 50-Year Benchmark

Surveys in 1953 and 1969 yielded similar densities of about one clam/m^2. Recruitment data from the 1950's comparable to the present surveys were 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.

Isle of Wight Bay

a) 2003 Status

This bay had the highest clam density of the Maryland coastal ecosystem, averaging 0.32 clams/m^2 from 21 samples (Figure 8.4.2). The observed natural mortality was 2.0%. The average length was 75.0 mm, with 13.3% of the population between 31 mm and 50 mm.

b) 9-Year Trend

Isle of Wight Bay placed first in clam densities during the past two years (Table 8.4.2, Figure 8.4.2), and over the 9-year period averaged 0.28 clams/m^2 from 144 samples (Table 8.4.1), barely edging out Chincoteague Bay for second place. Observed natural mortality was the lowest of the Coastal Bays, with boxes accounting for 2.0% of the population. This bay enjoyed good recruitment over the past few years, with the proportion of clams smaller than 51 mm averaging 23.9% over the 9-year period and peaking at 46.9% in 2002 (Figure 8.4.4). This was reflected in the lower average length of the sampled population, 69.6 mm.

c) 50-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 second among the Coastal Bays. Historic recruitment data comparable to the present surveys were not available.

Assawoman Bay

a) 2003 Status

A total of 15 stations (Figure 8.4.1) yielded an average density of 0.18 live clams/m^2 (Figure 8.4.2) and an observed natural mortality of 4.2%. The average length of the sampled population was 68.5 mm, with 15.9% of the clams between 31 mm and 50 mm.

b) 9-Year Trend

Clam densities were low relative to most of the other Coastal Bays, although fairly stable (Figure 8.4.3). The 9-year average of 0.16 clams/m^2, based on 120 samples, was slightly higher than Newport Bay (Tables 8.4.1 and 8.4.2). The observed mortality was also consistently low, averaging 4.2%. Recruitment was poor during the mid-1990's but jumped in 2000 (Figure8.4.4). Like Isle of Wight Bay, the peak year was 2002, when 42.1 % of the clams were under 51 mm. This trend is reflected in the average lengths, which went from 80.6 mm in 1996 to 58.7 mm in 2002, resulting in a 9-year average of 73.1 mm.

c) 50-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. Historic recruitment data comparable to the present surveys were not available.

St. Martin River

a) Recent Status

This coastal tributary was surveyed in 1996 and 1997, when a total of 40 samples were taken (Table 8.4.1). Clams were observed at only 52% of the stations, whereas in the bays they were found at almost 100% of the stations. Clam densities were the lowest of any Coastal Bays region, averaging 0.03 clams/m^2 in 1996 and 0.04 clams/m^2 in 1997 (Figure 8.4.3). Clam lengths were the largest of the Coastal Bays, averaging 85.2 mm for the two years. No clams were smaller than 51 mm in length. This river has been closed to shellfish harvesting for many years.

b) 50-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 (Table 8.4.1). However, this figure was based on only three stations. Historic recruitment data comparable to the present surveys were not available.

Hard Clam Summary

Current hard clam densities in all of the bays were lower than historic levels. Although closed to shellfish harvesting, the St. Martin River historically had the lowest clam densities in the Coastal Bays. The Coastal Bays populations were dominated by older, larger clams, with recruitment generally low and sporadic in most areas except in parts of Sinepuxent and Isle of Wight Bays.

C. Oysters

Introduction

The Eastern oyster (*Crassostrea virginica*), also known as the Chincoteague oyster, 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. 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 its 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, benefiting the newly settled juveniles and small adults of numerous species, including hard clams. 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, whether natural or cultured, 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 as well as the gradual disappearance of a significant structural element.

Oyster Data Sets

Yates oyster bars survey of 1907.

Maryland Conservation Bureau; Maryland Conservation Department; Maryland 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 are detailed.

DNR oyster bars survey of 1994. This survey revisits the old Yates bars. Data include surface shell per 1.5 minute dredge tow and associated species. No oysters were found.

DNR 1994-1995. Intertidal survey of Chincoteague Bay. Data include molluscan species, abundance (live and dead), and sizes per 0.25 m^2 quadrat.

DNR 1994-1995. Oyster survivorship study in Chincoteague Bay. Data include survivorship, growth, disease, and predation from arrays of suspended bags containing hatchery reared oysters.

DNR 1999-present. Dynamics of an intertidal oyster population in West Ocean City. 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 analysis.

Management Objective: none

Oyster Indicators:

A. Primary (all species)
  1. Density (# live/unit area)
  2. Geographic Distribution (latitude/longitude; 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 Analyses

In 1994, formerly charted oyster bars were sampled by handscrape at 150 locations throughout Chincoteague Bay. For details, see Tarnowski 1997c.

Results: Oyster Status and Trends

1. Recent Status

Presently there are no viable oyster populations inhabiting the subtidal bars of the Coastal Bays.

In addition to the 150 handscrape tows on the former oyster bars of Chincoteague Bay, more than 1,500 clam dredge stations throughout the coastal system, many of them on the old oyster grounds, were sampled over the past ten years and never has a live oyster been found. To a large extent, the bars themselves have been buried by sediment, greatly reducing this ecologically important habitat (Figure 8.4.5).

Small, relict 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. MDNR Shellfish Program has been monitoring one such population in West Ocean City since 1999 (Figure 8.4.6). Despite the long-term absence of significant oyster populations, two oyster diseases, Dermo (*Perkinsus marinus*) and SSO (*Haplosporidium costalis*), are still active in the Coastal Bays.

2. Historical Trends

The Yates Survey of 1907 identified 1,665 acres of oyster bars in the Coastal Bays, all confined to Chincoteague Bay (Figure 8.4.5). No bars existed in the upper bays because the salinity was too low 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, 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 1950's. 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 as well as the gradual disappearance of a significant structural element.

C. Bay Scallops

Introduction

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 or underlain by soft sediments), although they can also be found on other firm substrates such as shell and hard sand. Traditionally, scallops have been appreciated both for their succulent flavor and the aesthetic value of their shells.

Scallop Data Sets

Data sets for scallops are identical to those used for hard clams.

Management Objective: Re-establish bay scallop populations in the bays (FW 1.3).

Bay Scallop Indicators:

Primary (all species)
- Scallop Indicator 1: Density (# live/unit area)
- Scallop Indicator 2: Geographic Distribution

Secondary (species of particular interest)
1. Size-Frequency Distribution (% frequency)

Results: Scallop Status and Trends

Current Status

Bay scallops have been found in all of the Coastal Bays except Newport Bay, albeit in very low numbers (Figure 8.4.7). Scallops were caught at about 4% of the 2003 Hard Clam Survey stations, primarily in northern Chincoteague Bay, Sinepuxent Bay, and Isle of Wight Bay. These were all from the 2002 year class, ranging in lengths from 30 mm to 43 mm.

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 1920's 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, their preferred habitat had been largely eliminated by "wasting disease" during the early 1930's. Scallops made a brief return to the Coastal Bays during the late 1960's but soon disappeared, most likely because the recovering seagrass beds were not extensive enough to sustain a population.

In an attempt to re-establish a population in Chincoteague Bay, the Maryland 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/Maryland state line. In 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.

Bay Scallops Summary

Although low densities suggest that the long-term viability of the bay scallop population is still in question, the extraordinarily rapid range expansion is a major step toward their establishment in the Coastal Bays.

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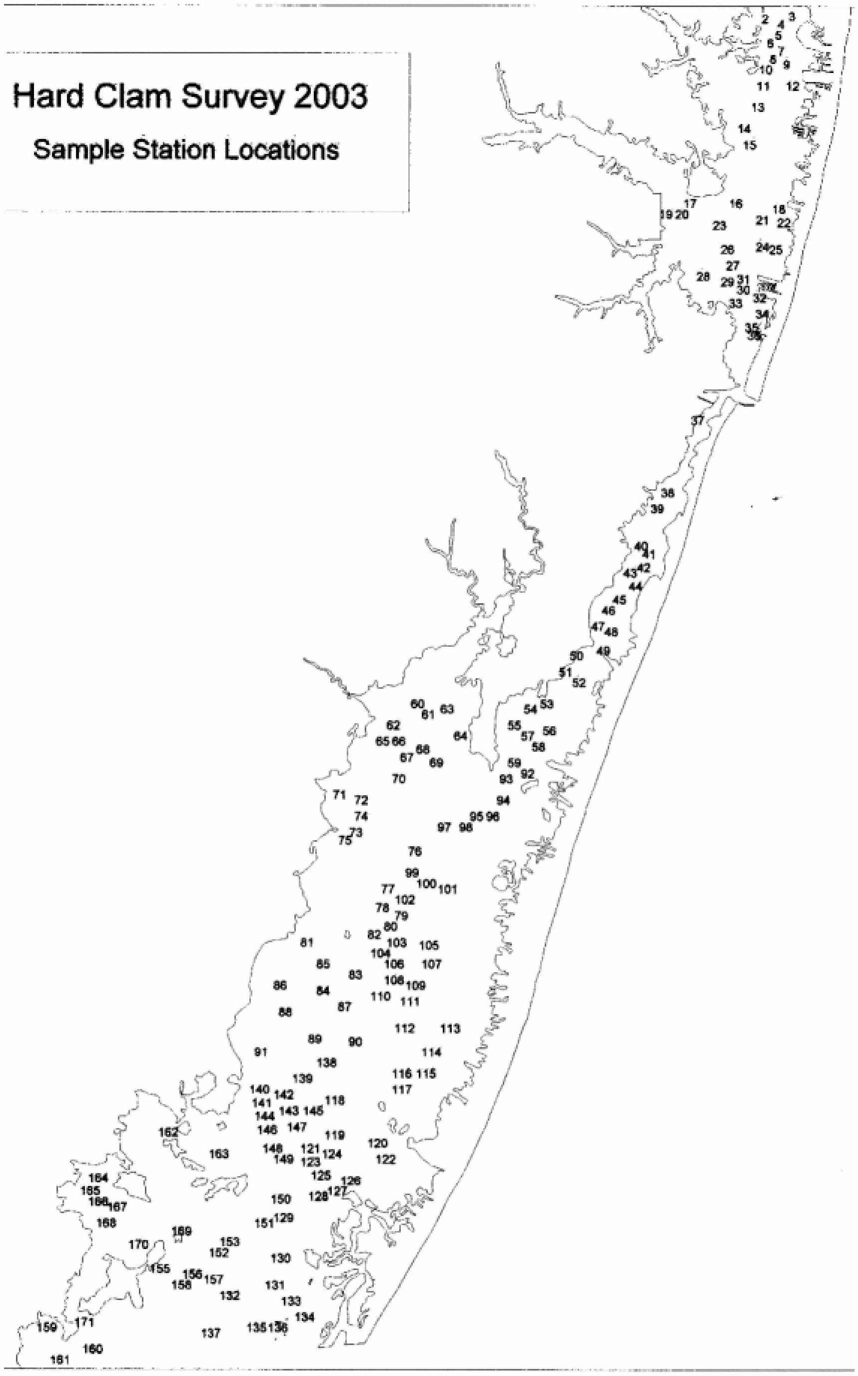

Figure 8.4.1: Hard clam survey station locations, 2003.

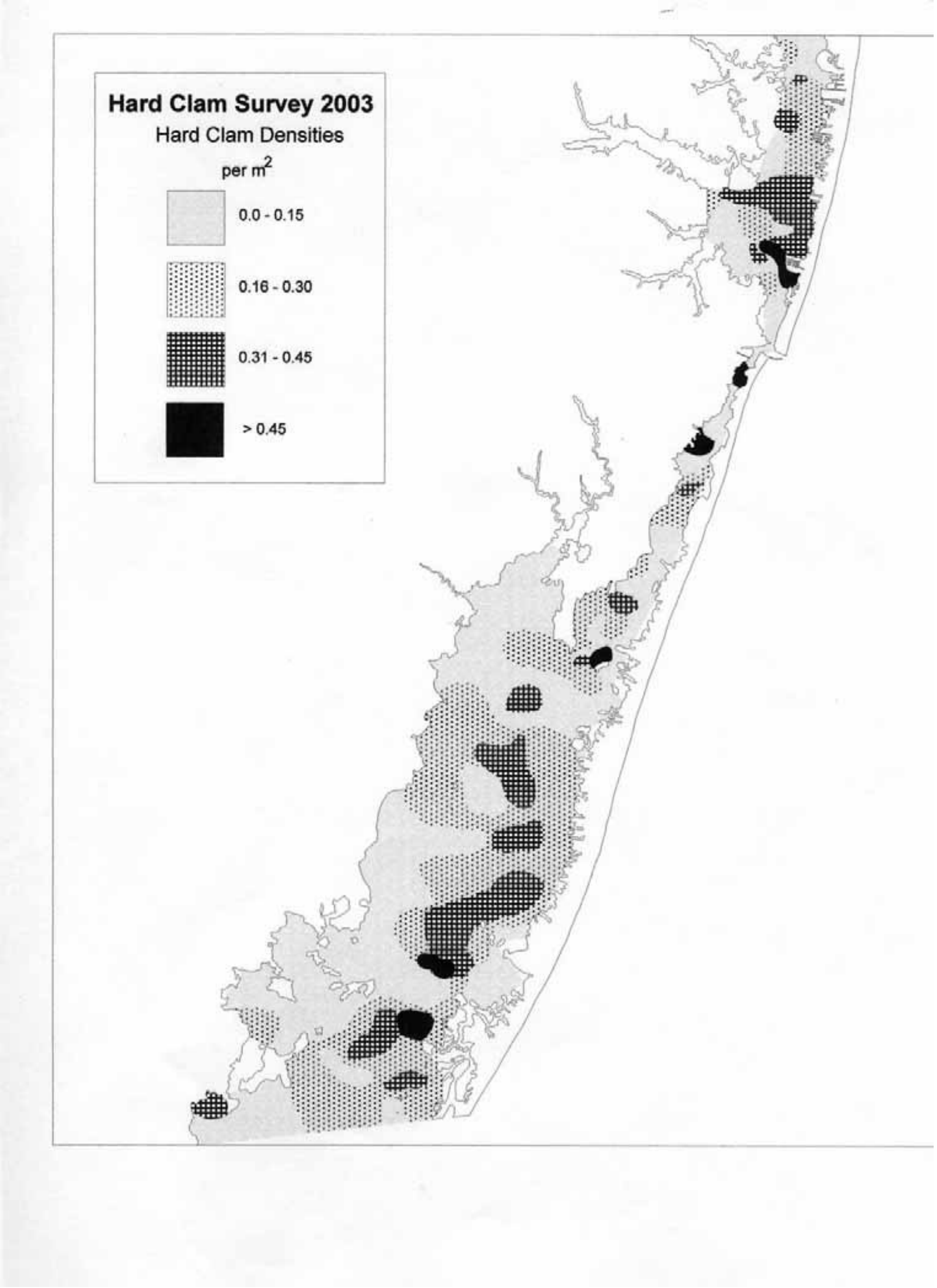

Figure 8.4.2: Hard clam densities based on 2003 hard clam survey. Clam density is measured in number of live clams/m^2.

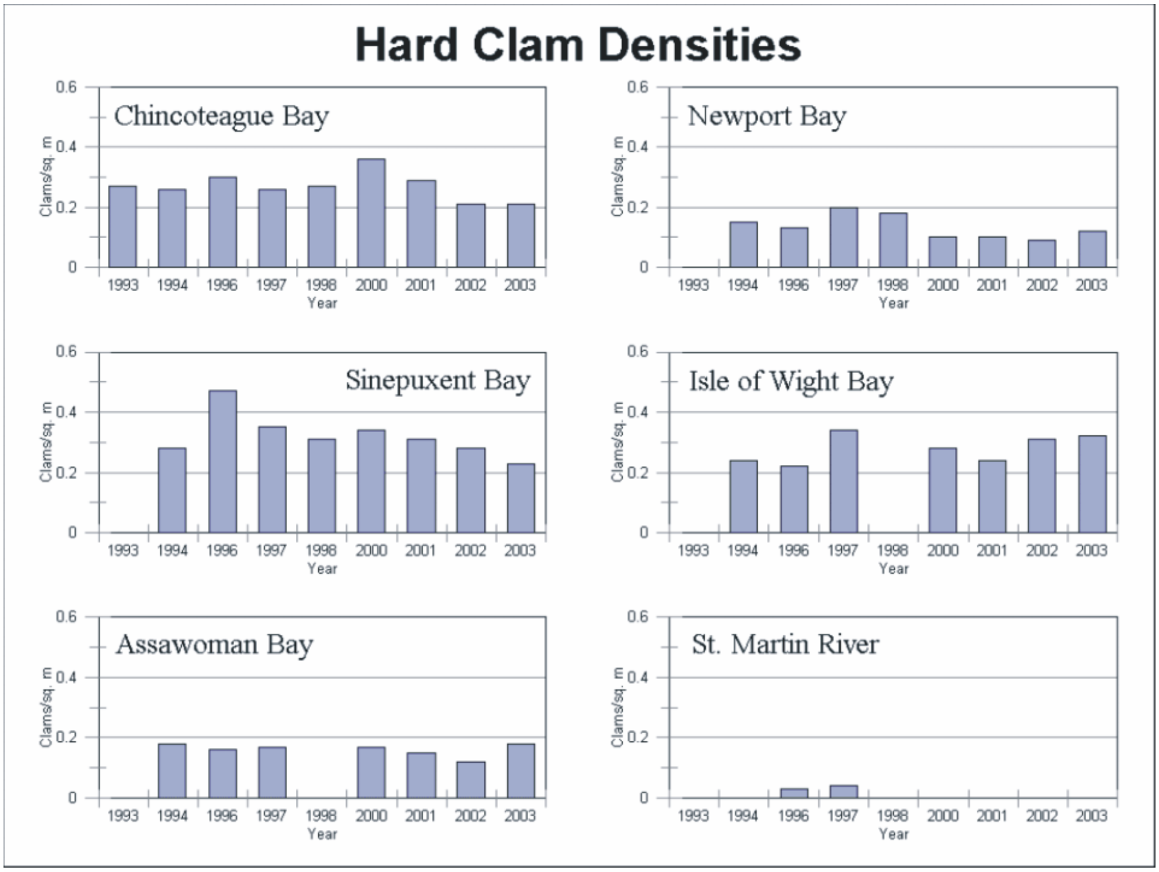

Figure 8.4.3: Hard clam densities per Coastal Bays segment, 1994-2003 trends. Only Chincoteague Bay was surveyed in 1993.

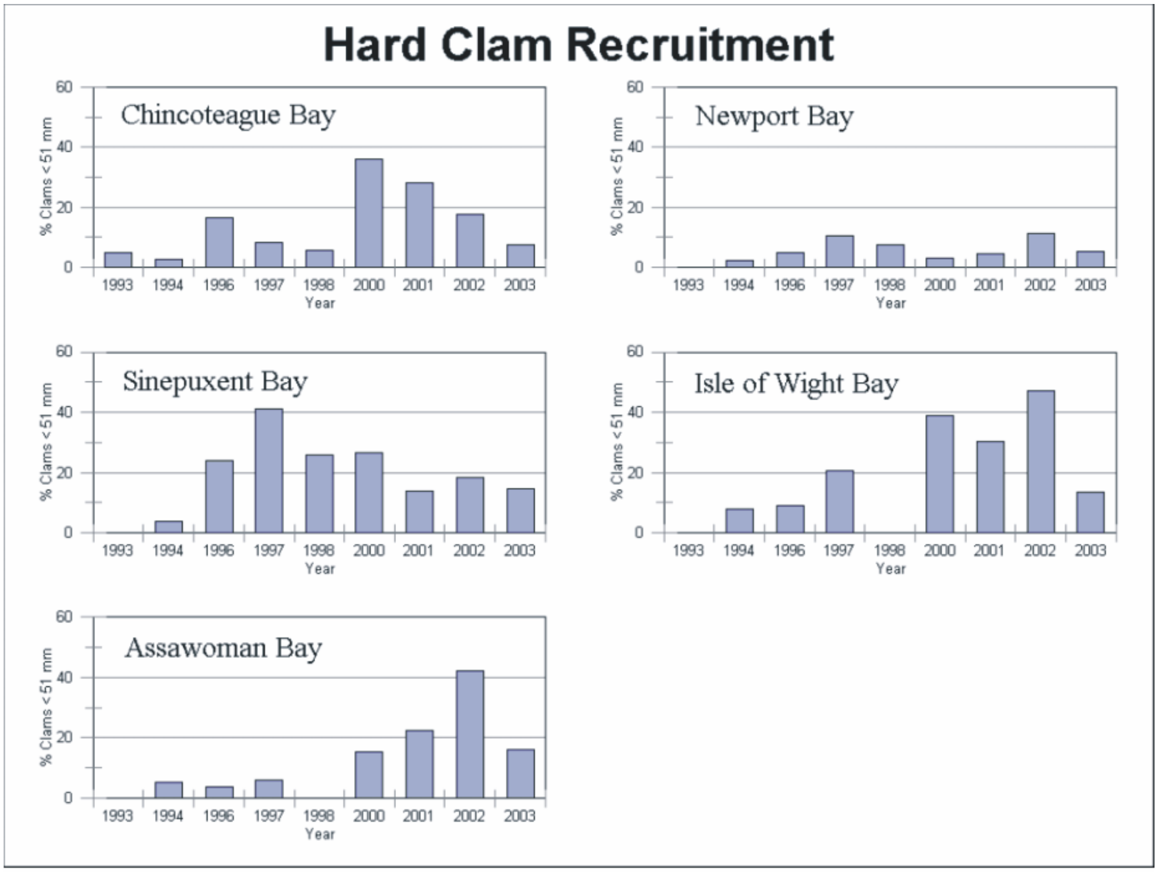

Figure 8.4.4: Hard clam recruitment per Coastal Bays segment, 1994-2003 trends. Only Chincoteague Bay was surveyed in 1993.

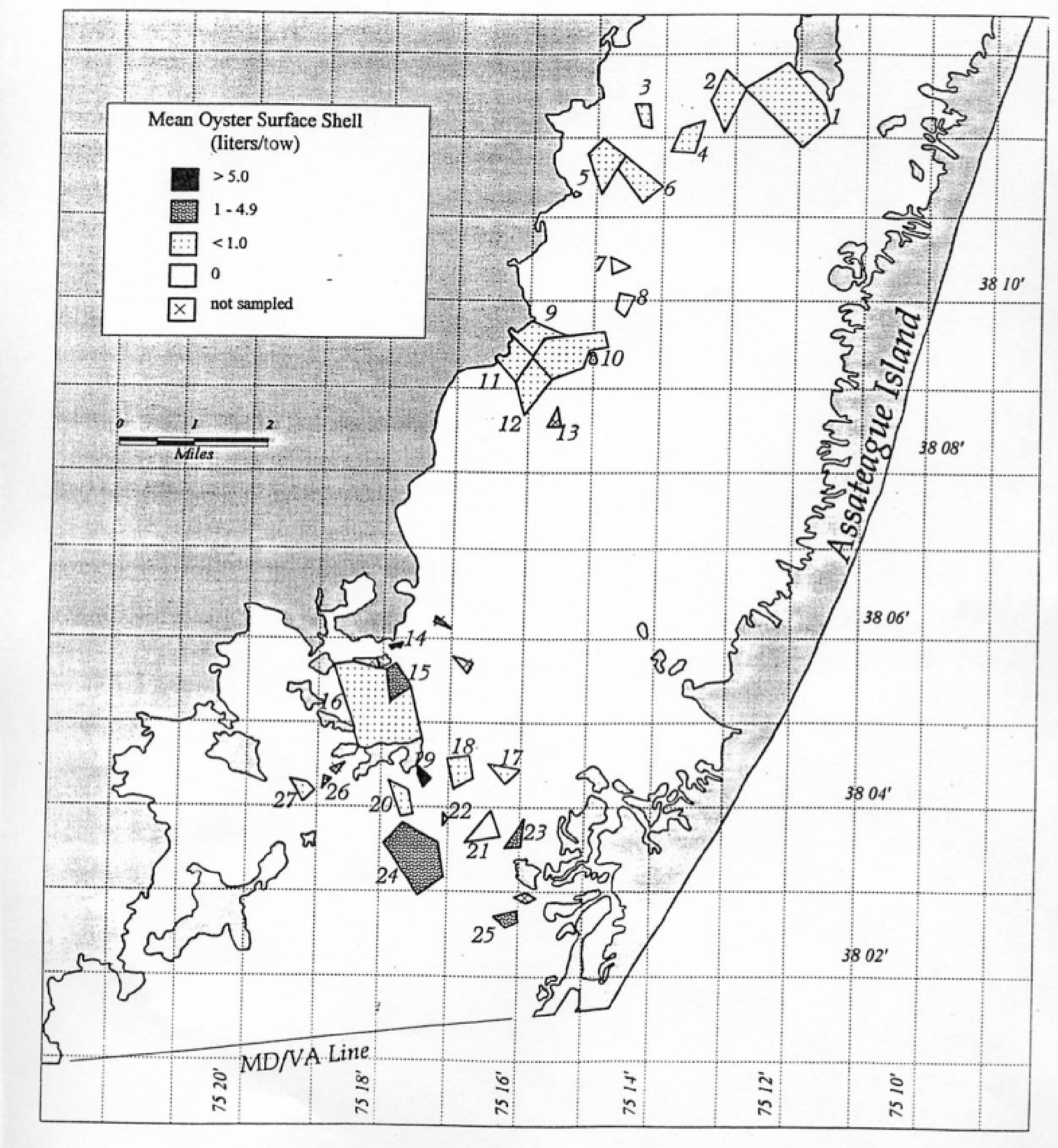

Figure 8.4.5: Oyster shell densities on former oyster bars in Chincoteague Bay, 2004.

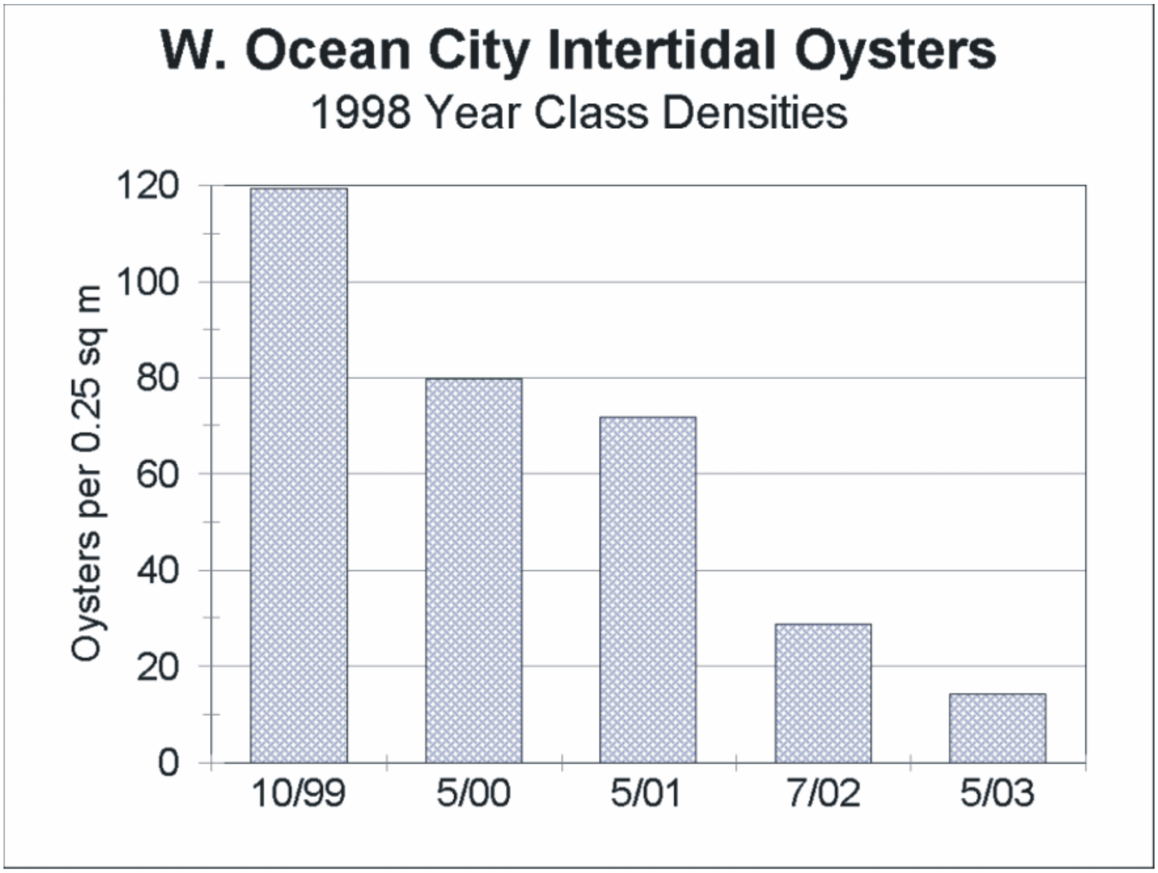

Figure 8.4.6: Trend in intertidal oyster densities near West Ocean City, 1999- 2003. Oysters are from 1998 year class.

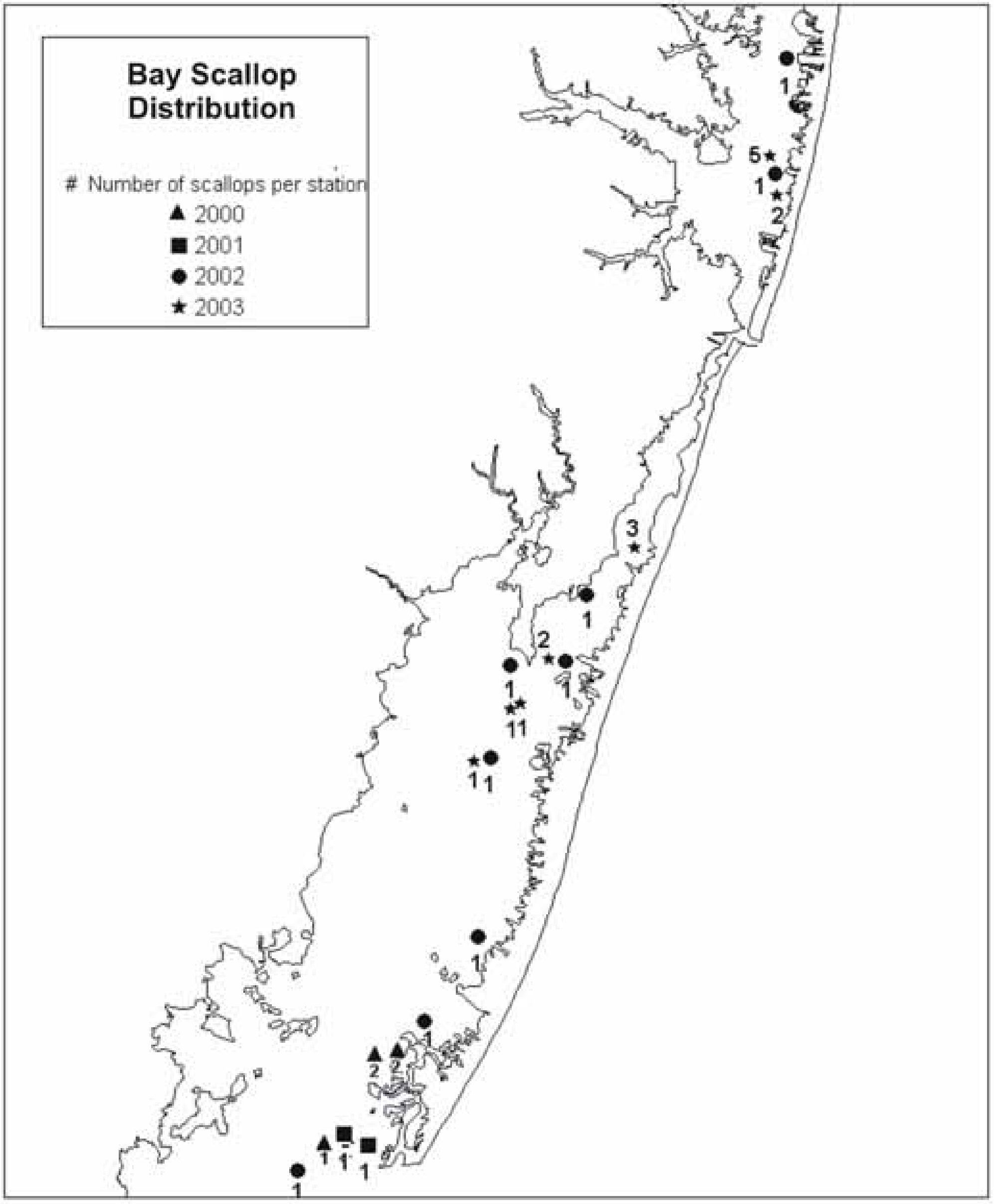

Figure 8.4.7: Bay scallops collected during clam surveys, 2000 - 2003. Numbers within map symbols represent the number of live bay scallops collected.

Chapter 8.5

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 sediments 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 annelid worms. Regions subjected to large environmental fluctuations are best monitored over time to assess the long-term response of the community and the relative influence of human-induced factors over the natural range of variability.

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 conditions are integrated over time.

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: Joint Assessment, Mid-Atlantic Integrated Assessment (MAIA), and the National Coastal Assessment, (NCA). The results presented in this report focuses on data collected during the National Coastal Assessment surveys between 2000 and 2001.

Management Objective: Maintain healthy benthic communities.

***Draft* Indicator:** MAIA benthic index > 3

Analyses

Benthic community condition analyses used the MAIA benthic index of biotic integrity (B-IBI). This index combines measures of abundance, number of taxa, Shannon-Wiener 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* (Llansó et al. 2002). Epifaunal organisms were eliminated from the analyses. The mean benthic index was calculated by averaging index scores for each of the 54 fixed stations visited in 2000 and 2001.

Status of benthic community

The status of the mean benthic index for 2000/2001 are presented below for each bay segment. Results for 2002 and 2003 are summarized separately since these studies were based on different stations than in 2000 and 2001 and therefore index scores could not be averaged for all years (see Llansó et al. 2003 and Llansó et al.2004 for annual conditions during these years).

Assawoman Bay

All sites met the benthic index goal in Assawoman Bay (Figure 8.5.1).

St. Martin River

Sites in the lower mainstem of the river met the benthic index goal, while sites in the prongs were either degraded or severely degraded (Figure 8.5.1). The upper Bishopville site that met the goal is a tidal fresh and may be inappropriately classified using this method. The sites in the upper river and prongs were classified as severely degraded both years - scoring low on almost every measure. The station at the mouth of Bishopville Prong that was classified as degraded had low abundance, low taxa and low bivalve scores. The upper Shingle Landing Prong station (on Middle Branch) was classified as degraded but may be inappropriately classified using this method because it is a tidal fresh water station although stream indices rate this area as very poor (see Chapter 3.1)

Isle of Wight Bay

All sites met the benthic index goal, except Manklin Creek, upper Turville Creek, and Herring Creek (Figure 8.5.1). Manklin Creek had low diversity and bivalve scores. Herring Creek contained acceptable levels of bivalves, while Turville Creek scored low for all measures.

Sinepuxent Bay

All sites, except two, met the benthic index goal (Figure 8.5.1). One site that did not meet the goal was in the commercial harbor and was dominated by annelid worms resulting in a low diversity score. The other site was in the middle of Sinepuxent Bay, which was only moderately degraded due to a low bivalve metric score (indicating an impaired condition).

Newport Bay

All sites in this bay proper passed the benthic index goal (Figure 8.5.1). Sites in Trappe, Ayer, and Newport Creek were degraded (the upper Newport Creek site that passed is classified as oligohaline and may be inappropriately classified using this method).

Ayer and Newport sites changed salinity classification between 2000 and 2001 (Newport changed from mesohaline to polyhaline and Ayer Creek from oligohaline to mesohaline). One station, ASIS 4, at the mouth of Trappe Creek also changed salinity classification from mesohaline to polyhaline. Results should be interpreted with caution since strong shifts in salinity at these locations affect the way the results are calculated more than environmental degradation.

Newport Creek contained mostly annelid worms and Ayer Creek had low abundance and bivalve scores. Trappe Creek was only moderately degraded.

Chincoteague Bay

All sites meet the benthic index goal (Figure 8.5.1).

2000 and 2001 annual results: Of the 54 stations sampled, 42 and 33 sites exhibited healthy benthic communities in 2000 and 2001 respectively, (77.8 and 61%) and between 12 and 21 sites (22.2 and 39% respectively) exhibited degraded conditions (Llansó et. al 2001, Llansó et. al 2002).

2002 spatial distribution: Of the 124 sites sampled in 2002, 95 sites (77%) exhibited healthy benthic communities (index score equal to or greater than 3.0) and 29 (23%) exhibited degraded benthos (index score < 3.0) (Figure 8.5.2). Of the 29 sites that failed, 18 were classified as severely degraded and 11 were classified as degraded by the index (Llansó et. al. 2003).

2003 spatial distribution: Of the 152 sites sampled in 2003, 136 sites (89.5%) exhibited healthy benthic communities (index score equal to or greater than 3.0) and 16 (10.5%) exhibited degraded benthos (index score < 3.0) (Figure 8.5.3). Of the sites that failed, 10 were classified as severely degraded and 6 were classified as moderately degraded by the index (Llansó et. al. 2004).

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 1-3 species, usually annelids.

Monitoring of biological communities in 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 (Llansó *et al.* 2002).

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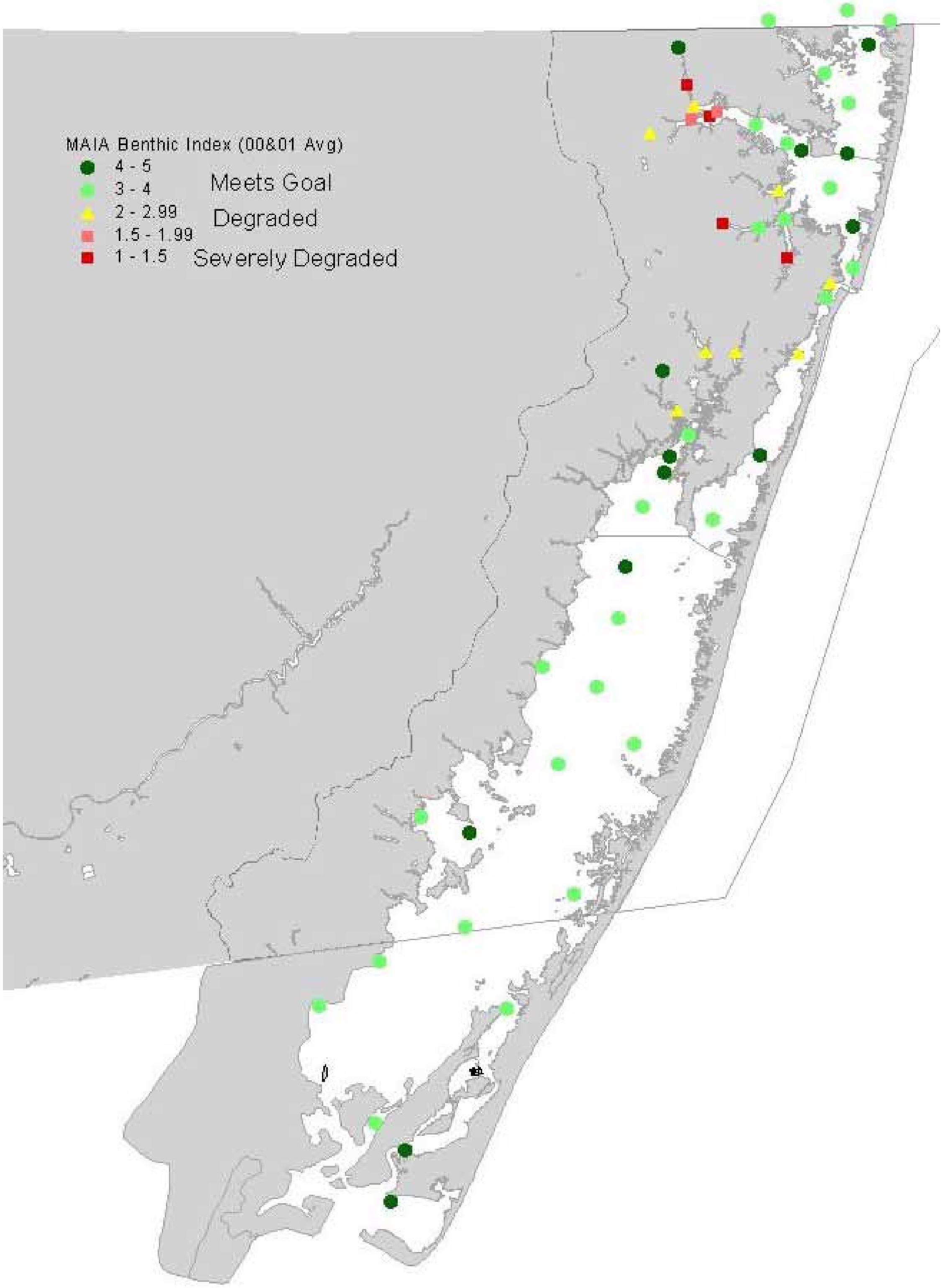

Figure 8.5.1: Benthic index of biotic integrity values calculated based on 2000-2001 mean survey results for 54 stations throughout the Coastal Bays.

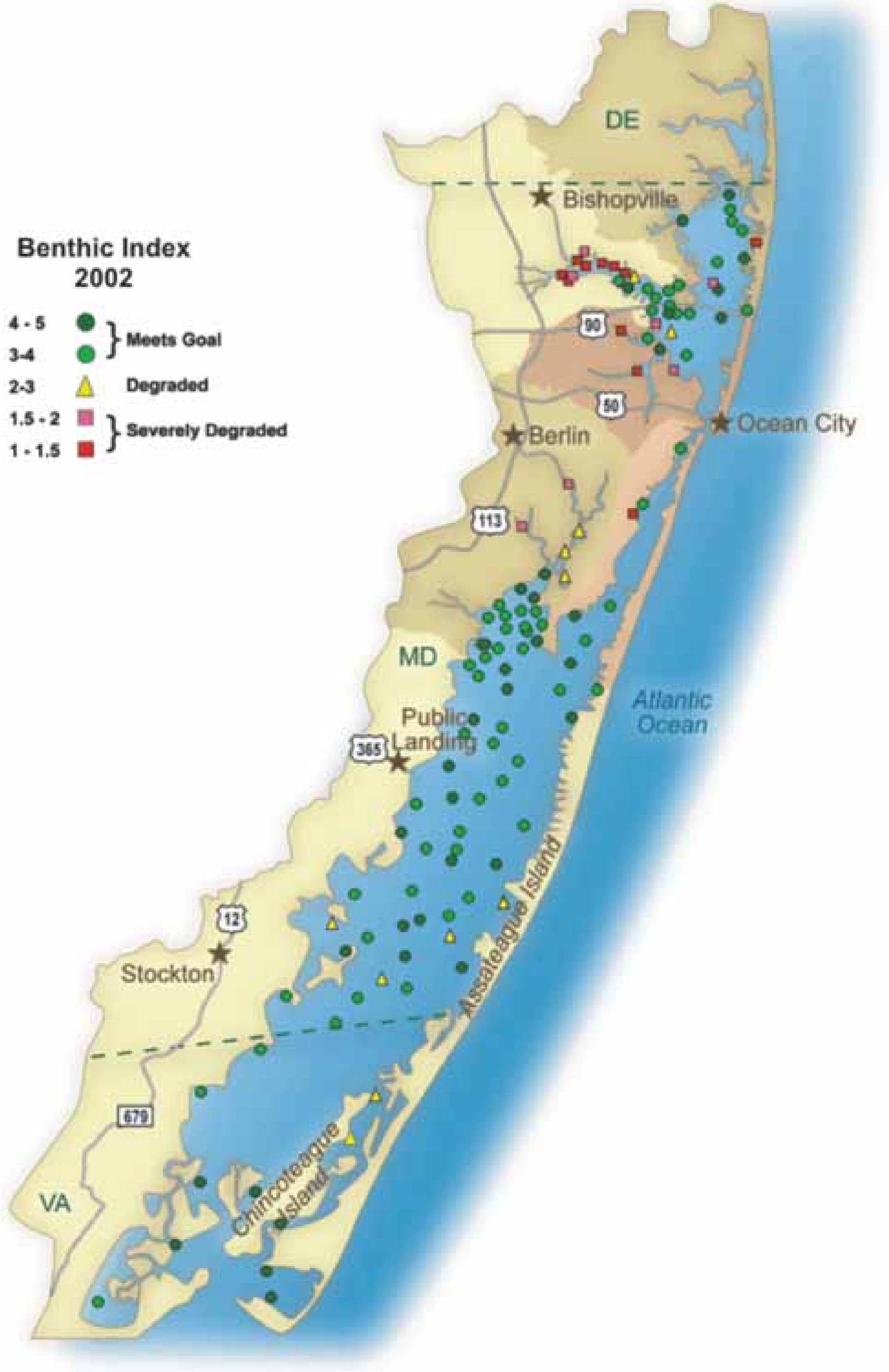

Figure 8.5.2: Benthic index of biotic integrity values calculated based on 2002 survey results for 124stations throughout the Coastal Bays.

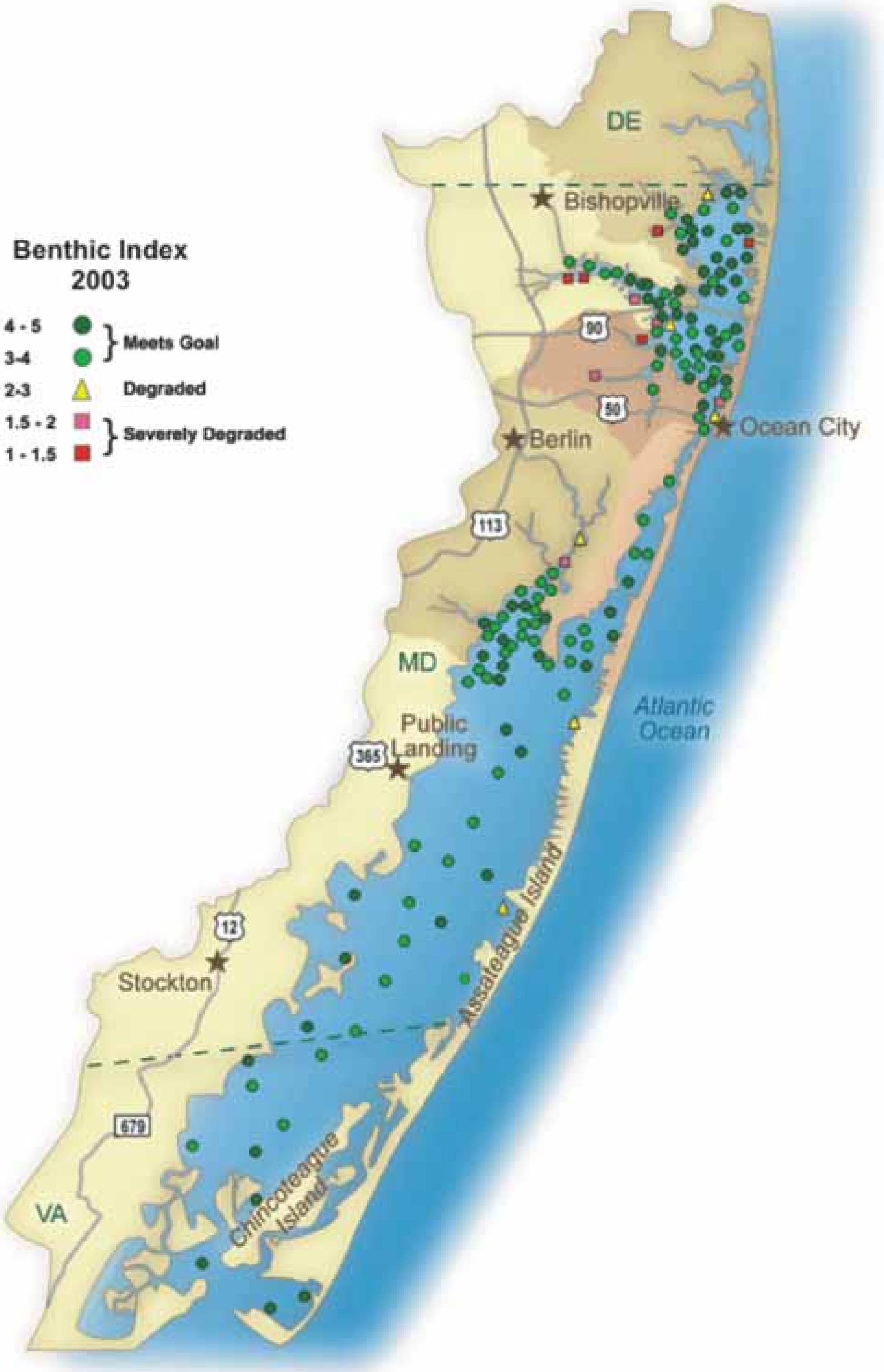

Figure 8.5.3: Benthic index of biotic integrity values calculated based on 2003 survey results for 152 stations throughout the Coastal Bays.

Chapter 8.6

Status of blue crab, *Callinectes sapidus,* populations in the Maryland Coastal Bays

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Abstract

The blue crab, *Callinectes sapidus,* is a valuable resource in the Coastal Bays, supporting a steady commercial and recreational fishery. Surveys suggest that blue crab abundance fluctuates without an apparent trend, yet there is still a successful annual commercial fishery that even attracts crabbers from the Chesapeake Bay. Since 1990, commercial landings for crabs have averaged from 0.5 to 1.5 million pounds. Commercial landings for 2003 were 1.17 million pounds. Unlike Chesapeake Bay landings data, these appear to fluctuate without trend. During 2003, the fishery independent trawl and seine survey caught a total of 6,754 blue crabs. An examination of 2,627 legal blue crabs taken by trawl net over a 13- year period indicates no decline in average size, suggesting minimal increases in fishing pressure. Like commercial landings, these catches have generally fluctuated without trend.

Environmental and hydrographic factors play a key role in blue crab recruitment (movement into the Coastal Bays). One factor that may affect blue crab populations is a parasite (*Hematodinium* sp.) that kills crabs in late summer and fall. Blue crabs may also be threatened by the presence of invasive species such as green and Asian shore crabs (*Carcinus maenas* and *Hemigrapsus sanguineus*).

A. Blue crab abundance

Introduction

The blue crab, *Callinectes sapidus*, is a valuable resource to the Coastal Bays ecosystem and the commercial and recreational efforts it supports. Since 1990, commercial landings for crabs have averaged from 0.5 to 1.5 million pounds annually. The Coastal Bays Fisheries project (CBFI) has conducted annual surveys of the Coastal Bays since 1972. Although blue crab monitoring is not an official component of the CBFI, some data is available through the CBFI and through reported catch data.

Management Objective: Maintain optimum sustainable blue crab populations (MCBP CCMP objective FW 1.4)

Draft **Blue crab Indicator:** Abundance/ trends

Analyses

Abundance – commercial landings, independent trawl survey mean size comparison (Casey et al. 2001b).

Hematodinium – occurrence, relationship to salinity, temporal variability.

Status of blue crab abundance

Commercial landings from these bays for 2003 were 1,168,960 pounds. Unlike the Chesapeake Bay, these Coastal Bays landings appear to fluctuate without trend (table 8.6.1). During 2003, the fishery independent trawl and seine survey caught a total of 6,754 blue crabs. Like commercial landings, these catches have generally fluctuated without trend (Figure 8.6.1).

Table 8.6.1 Reported Landings of Hard, soft and peeler crabs (in Pounds) in Coastal Atlantic Waters under the jurisdiction of the State of Maryland.

Year	**Landings (Pounds)**
1997	1,146,487
1998	541,292
1999	561,216
2000	1,422,277
2001	1,881,068
2002	1,168,469
2003	1,168,960
AVERAGE	**1,165,824**

An examination of 2,627 legal blue crabs taken by trawl net over a 13 year period indicates no decline in the mean size (~140 mm), which might otherwise indicate increasing fishing pressure (Casey et al. 2001b). An examination of mean size from trawl caught blue crabs from 1991 through 2001 indicated a size variation from 137.6mm (5.42 inches) to 142.8mm (5.62 inches).

Indirect information suggests that spawning and recruitment of blue crabs in the Coastal Bays system may vary from that of the Chesapeake Bay. Water circulation is slow and, in many areas, larvae may be entrained in the bay system rather than being carried out on currents. At certain times of the year, megalops stage larvae of the blue crab were found to be abundant in the vicinity of the Chincoteague and Ocean City inlets. This, along with other factors, suggests that a substantial number of crabs may be recruited from other sources to these bays. This possibility should be examined further.

During the winters of 2000 and 2003, a total of 64 sites were examined to locate the overwintering sites of mature female blue crabs. Like female crabs in the Chesapeake, Coastal Bays females appear to seek out the deepest waters for overwintering, constituting the largest percentage by sex of crabs using these sites. In the northern bays of Assawoman, Isle of Wight and Sinepuxent, these areas are represented by the dredged navigation channels. However, in Newport and Chincoteague Bays to the south, no such dredged channels exist. Here, the mature female crabs appear to still seek the deeper water (7 to 9 feet), but are found intermixed with immature males and females as well as mature males (Casey 2004, in review).

B. Parasitic infection

General Introduction

Hematodinium sp. is a parasitic dinoflagellate that infects and kills blue crabs. Outbreaks of disease caused by *Hematodinium* sp. in blue crabs have been reported in several coastal states. In the laboratory, experimentally infected blue crabs suffer high mortality rates (>86%) to the resultant disease, a level seven to eight times higher than uninfected controls. Current models project crab abundance based on constant low levels of natural mortality. They do not consider the potential epizootics and resulting mortalities caused by *Hematodinium* sp. or other diseases.

Several commercially important crustaceans have been reported infected with *Hematodinium* spp. including the Tanner crab (*Chionoecetes bairdi*), the snow crab (*Chionoecetes opilo*), the Norway lobster (*Nephrops norvegicus*), the velvet swimming crab (*Necora puber*), and the blue crab (*Callinectes sapidus*) in the U.S.A. Other commercial species are also hosts to *Hematodinium* sp. infections, including 2 species of rock crabs (*Cancer irroratus* and *C. borealis)*, the Australian blue crab (*Portunus pelagicus*), and the mangrove crab (*Scylla serrata*). Infections also occur in lady crabs (*Ovalipes ocellatus*), obligate coral-dwelling crabs, and amphipods.

Hematodinium sp. in the Coastal Bays

In 1992 watermen from Maryland Coastal Bays reported crabs dying in their baited crab pots. Upon investigation, adult and juvenile blue crabs from Coastal Bays of Maryland, Delaware, and Virginia were found infected with *Hematodinium* sp., a parasitic dinoflagellate. Dinoflagellates were found in hemolymph and tissues of sick crabs where the parasite proliferates and causes mortalities. Studies conducted since 1992 have indicated that in coastal bays of the Delmarva region, prevalence of infected crabs follows a seasonal pattern with up to 90% of crabs infected during early winter. Heavy mortalities were reported by watermen during summer months.

Blue crabs infected with *Hematodinium* sp. have been reported in other areas along the Atlantic and Gulf Coasts (Newman & Johnson 1975, Couch & Martin 1982, Overstreet

1978). Prevalence of infected crabs varied depending upon location, and infections were found more often in shallow the Coastal Bays than in deeper, larger estuaries.

Crustaceans other than blue crabs are also affected by *Hematodinium* spp. dinoflagellates; these included amphipods, green crabs, Tanner crabs, and other commercially important species.

Prevalence of *Hematodinium* sp. infections in blue crabs is seasonal. The seasonal infection cycle and apparent salinity and temperature requirements for infections indicate that environmental factors influence the parasite's ability to proliferate within crab hemolymph. Additionally, host factors such as size influence the prevalence of infections. The prevalence and intensity of *Hematodinium* sp. in blue crabs are seasonal and peak in late autumn and early winter in Maryland coastal bays. The apparent 0% prevalence from late winter through spring in coastal bays of the Delmarva region (Messick 1994) is likely caused by low water temperature reducing *Hematodinium* sp. numbers to unobservable levels within the hemolymph. Winter temperatures appear to provide a refuge from infection for crabs overwintering in coastal bays of Delmarva.

Periodic outbreaks of dinoflagellate infections with subsequent high host mortalities prompted a study of the epizootiology and distribution of the crab pathogen beginning in 1992. Hemolymph samples from over 13,000 crabs were assessed for infections over eight years. Moderate to high prevalence were found at several locations along the Atlantic and Gulf coasts of the United States. In the Coastal Bays of Maryland and Virginia, prevalence followed a seasonal pattern with a sharp peak in late autumn. Infections were significantly more prevalent in crabs measuring less than 30 mm carapace width; host sex did not influence prevalence. Prevalences were highest in crabs collected from salinities of 26-30‰; no infected crabs were found in salinities below 11‰. Intensity of infection did not vary among crab sizes, molt stages, or sexes. Several other crustaceans, including gammaridean amphipods, xanthid (mud) crabs, and the green crab *Carcinus maenus*, were found with *Hematodinium*-like infections. Considering its widespread distribution and high pathogenicity, we suggest that *Hematodinium* sp. represents a significant threat to blue crab populations in high salinity estuaries along the Atlantic and Gulf coasts of the USA.

Blue crabs from the Coastal Bays had high prevalence of *Hematodinium* sp. infections, especially during autumn months. Within the Coastal Bays, the distribution of *Hematodinium* sp. was significantly associated with high salinities ($p<0.0001$). Prevalence was highest in the 26-30‰ salinity range with 38% infected ($n = 2,130$). No crabs collected from salinities <11‰ ($n = 45$) were found with infections. Prevalence of *Hematodinium* sp. varied significantly among 20 trawl stations ($p<0.0001$). Stations T01-T07, located north of Ocean City Inlet, were among the stations with the lowest prevalence. Additionally, stations T12 and T17 in the upper reaches of Newport Bay and Green Run Bay had relatively lower prevalence of infections than nearby stations (Figure 8.6.2). Average salinities at stations T05 and T12 were comparatively lower than nearby stations (Figure 8.6.2).

Hydrographic features may contribute to epizootics of *Hematodinium* sp. in blue crabs. In the Coastal Bays, the prevalence of *Hematodinium* sp. varied by location in relation to salinity, and to general drainage or flushing patterns. Stations with some of the lowest prevalence were located north of the ocean inlet, and in tributaries (Figure 8.6.2). The greatest drainage of this system is into the northern portions (Sieling 1960); i.e., increased flushing via this drainage pattern may partially explain the lower prevalence of infections in the northern Coastal Bays. Hydrographic conditions may contribute to high prevalence of infections in crabs from Chincoteague Bay, Wachapreague, Virginia, and Red Bank Creek, Virginia. Limited flow of water through these shallow, high salinity lagoons may focus or amplify the infectious stages of the parasites. The region includes relatively closed crab populations, based on low immigration and emigration rates of juveniles and adults, relatively high salinity with little water exchange between the open ocean and backwaters, and stressful conditions such as high temperatures and seasonal hypoxia. Similar conditions exist in many small estuaries along the mid-Atlantic and southeastern USA.

Management Objective: Maintain optimum sustainable blue crab populations (FW 1.4)

***Draft* Blue crab Indicator:** *Hematodinium* infection

Status of Hematodinium Infection

A. 2003 Field Studies

Crabs from Maryland Coastal Bays were sampled June 17-20, 2003. A total of 76 crabs were assayed for disease via a hemolymph smear. *Hematodinium* was present in 11% of assayed crabs. Average size of crabs was 66.4 mm carapace width.

Crabs were collected from Ed Lynch, a local waterman, on July 8th, 2004. He is a coastal bay waterman who was complaining of crabs dying in his pots and on the way to the market. Approximately 50% of crabs he selected as being sick had *Hematodinium* sp. in their hemolymph.

Crabs from Maryland Coastal Bays were sampled in July, August, and September. A total of 434 crabs were assayed for disease via hemolymph smears during this quarter. Results showed a 12 to 33% infection rate.

Table 8.6.2: Results of blue crabs assayed for *Hematodinium* prevalence in 2003.

Month	# Crabs sampled	% Prevalence of Hematodinium	Average crab size (mm)
July	319	23	92
August	33	0	79
September	82	12	102

B. Experimental Studies

Past Experimental Studies **-***Hematodinium* sp. infections in blue crabs from the United States are widely distributed and prevalence is influenced by location, salinity, and host size (Messick 1994, Messick & Shields 2000). Seasonal infection cycle and apparent salinity and temperature requirements for infections in wild crab populations indicate that environmental factors influence the parasite's ability to proliferate within crab hemolymph. A series of experiments found that low water temperature and salinity limit the proliferation of *Hematodinium* sp. in blue crab hemolymph (Messick 1999; Jordan et al. 1999). Blue crabs that were experimentally infected with 10^3 or 10^5 cells of *Hematodinium* sp. began dying 14 days post injection with a median time to death of 30.3 ±1.5d (SE). Subsequent mortality rates were 86% in infected crabs as opposed to 20% in control animals (Shields and Squyars 2000).

Current Experimental Studies **–** Blue crab population models do not consider the effects of epizootics and resulting mortalities caused by *Hematodinium* sp. or other diseases in their projections of crab abundance (Lipcius & Van Engel 1990; Abbe and Stagg 1996; Rugolo et al. 1998). Mortality rates and time to death in infected blue crabs would give an estimate of mortality based on infection level. The goal of current research is to experimentally assay days to mortality in crabs experimentally infected with a known density of parasite. Shields and Squyers (2000) conducted similar experiments in crabs inoculated with known quantities of *Hematodinium* sp., but did not detect a significant variation in mortality between two parasite density inoculums. National Oceanic and Atmospheric Administration, NOAA, plans to assay mortality between two size categories in crabs inoculated with a known parasite density. This information will give blue crab fishery managers a better estimate of mortality in crab populations affected by the parasitic dinoflagellate, *Hematodinium* sp.

Overall Summary

Blue crab abundance is fluctuating without trend yet there is still a successful annual commercial fishery that even attracts crabbers from the Chesapeake Bay. Environmental/hydrographic factors play a key role in blue crab recruitment. One factor that may affect blue crab populations is a parasite that infects crabs and is believed to kill crabs in August. Blue crabs may also be threatened by the presence of invasive crabs such as the green crab and the Pacific Shore crab.

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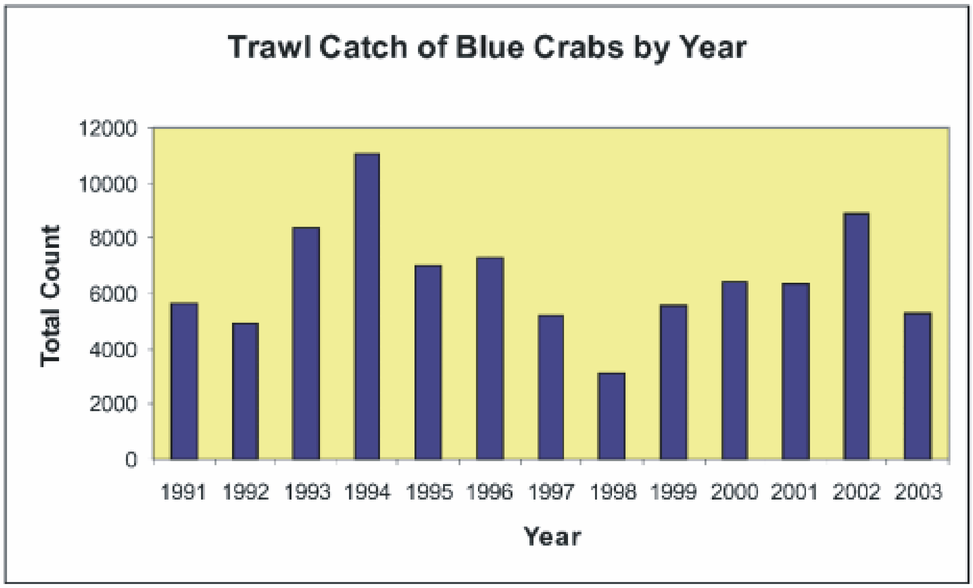

Figure 8.6.1: Annual blue crab landing during the DNR fisheries trawl survey.

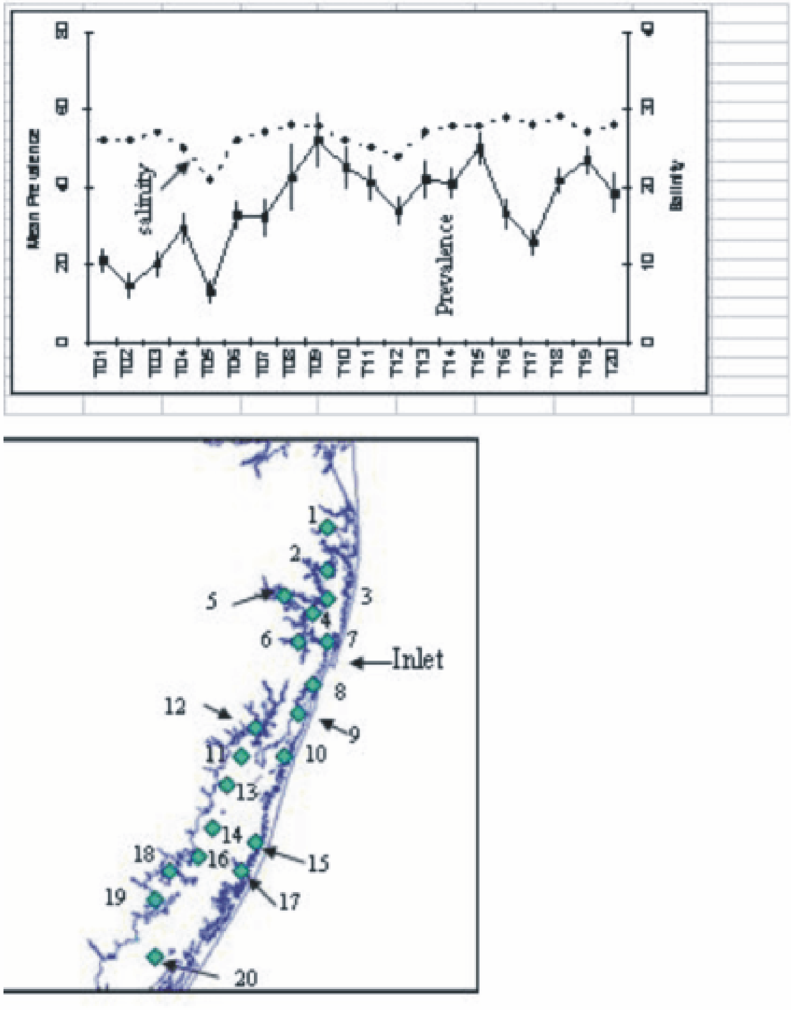

Figure 8.6.2: Prevalence of *Hematodinium spp*. parasite in blue crabs from Coastal Bays stations, 2003.

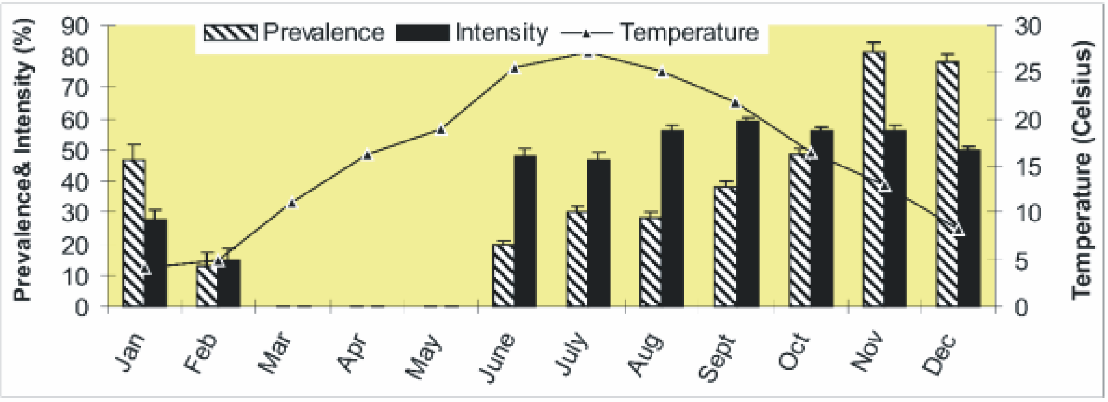

Figure 8.6.3: Prevalence and intensity of *Hematodinium* infection among months (2003).

Chapter 8.7

Status of horseshoe crab, *Limulus polyphemus*, populations in the Maryland Coastal Bays

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Introduction

Horseshoe crabs, *Limulus polyphemus*, are characterized by high fecundity, high egg and larval mortality and low adult mortality (Botton and 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 and 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. Since the early 1990’s, horseshoe crabs have been harvested as bait to catch American eel (*Anguilla rostrata*) 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. The blood of the horseshoe crab is not only unique but it provides 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

DNR data on north Assateague Island ongoing.
Volunteer monitoring program ongoing.

Horseshoe crab Indicator: ***none***

Status of horseshoe crab

The status of the horseshoe crab population in Maryland and the Atlantic Coastal Bays at this time is unknown. Efforts are underway to conduct population assessments through an interstate Federal Management Plan (FMP) under the auspices of the Atlantic States Marine Fisheries Commission (ASMFC). Seasonal and state harvest restrictions are currently in place.

The Interstate Fishery Management Plan for Horseshoe Crabs was approved by the ASMFC on October 22, 1998. The FMP 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 FMP are requirements for managing the horseshoe crab harvests and monitoring populations.

Requirements of the Horseshoe Crab FMP Addendum 1 include:

- States must reduce horseshoe crab landings to 25% below their reference period landings.
- State with more restrictive harvest limits are encouraged to maintain those limits.
- Encourage the NMFS to establish a horseshoe crab sanctuary at the mouth of the Delaware Bay estuary.

Recommendations of Horseshoe Crab FMP Addendum 2 include:

- Allow for the voluntary transfer of harvest quotas between states.

The complete Coast-wide FMP for horseshoe crabs can be found at ASMFC.

Summary

Horseshoe crabs are an important role in the ecosystem as well as an important commercial fishery. The status of the horseshoe crab population along the Atlantic coast is of great concern. The species serves as a primary bait source for several important commercial fisheries and is the backbone of a major medical process. Migratory and local shorebirds feed on horseshoe crab eggs in areas of high spawning densities and are considered essential to some birds. Despite significant shorebird predation on the eggs, such activity probably has little impact on the horseshoe crab population (Botton et al. 1994) compared to vanishing habitat in the Coastal Bays.

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Chapter 8.8

Status of the endangered piping plover, *Charadrius melodus*, population in the Maryland Coastal Bays

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Abstract

The Piping plover, a federally threatened species, restricts its mid-Atlantic breeding activities to early successional shorelines, which harbor an abundance of surface-dwelling prey. To date, the only portion of Assateague Island that has received sufficient tidal influence for cross-island overwash has been a 9.5 km (6 mile) section just south of the Ocean City Inlet, adjacent to the Sinepuxent Bay. Two significant tidal events (1992 and 1998) have helped maintain the early succession habitat in certain areas. For the past eight breeding seasons, the Piping plover breeding population has remained stable at around 60 pairs (and additional non-breeding birds). Although difficult to evaluate, it is possible that the population is at capacity for the available conditions.

Background

The ragged boundary of guts and marsh islands along the eastern edge of the southern Maryland Coastal Bays is a reminder of the historic influence of overwash events. These events provided pulses of energy and change, scouring inlet troughs, distributing sediment and altering water chemistry and circulation patterns.

Over the past century, stabilization efforts necessary for human development along Maryland's ocean beaches have dramatically reduced the influence of tidal events and bay hydrology. This manipulation reduced the tidal prism, bay water exchange rate, and the distribution of coastal sediments. In response, the Coastal Bays have suffered from reduced flushing rates, silting of back bay and creek bottoms, the prevention of saltmarsh expansion, and the impacts that these changes have had on the bay's chemistry, flora, and fauna.

The National Park Service stopped most of the beach stabilization activities on Assateague Island in the mid-1970's. The Park's management strategy is to allow natural tidal events to redefine the constructed primary dune line and ultimately return Assateague to a more natural barrier beach.

The island was not subjected to tidal influences of the magnitude necessary to erode the constructed primary dune system until the 1990's. A set of events, initially in 1991/92 and again in 1998, was successful in redistributing much of the constructed dune. Those overwash events moved beach sand partially across the island adjacent to the Chincoteague Bay, but not enough to influence the bay proper. The wash-over from these events was complete and even resulted in some migration along the island's northernmost 6-mile, often referred to as the 'north end'.

The north end had historically received only minimal alteration from beach stabilization and dredge disposal, but was subjected to a sediment transport deficit due to the influence of the Ocean City inlet jetties. The entrainment of beach sand along the north end resulted in enough beach loss to permit occasional overwash into the Sinepuxent Bay. The low island profile resulting from the periodic overwash had supported Maryland's only breeding population of the Piping plover, a small shorebird that was Federally listed as a Threatened Species in 1985.

The Piping plover restricts its mid-Atlantic breeding activities to early successional shorelines, which harbor an abundance of surface-dwelling prey. Breeding is most successful at inlets free of hardened structures, and within wide expanses of low-lying overwashed barrier spits and islands. Continuous linear dunes, hardened shorelines, and maturing vegetated communities are all avoided by plover for breeding purposes.

Based on Piping Plover population studies from 1986 through 1990 the Maryland breeding birds were concentrated along the north end and scattered pairs in low-lying sections elsewhere along the island. Plovers that successfully raised offspring were those that had access to the low, wet portions of wash-over fans and the bay intertidal beach. Pairs without access to overwashed areas tended to fail in raising young, and widespread failure occurred during years when the fans were closed by vegetation expansion. During the span of the research, the population had dropped from 25 to 14 pairs. Models of survival estimates predicted that local extinction could occur by 2016, short of some major changes to the island habitat.

Following an initial lag period after the 1992 overwash events, the Piping plover responded to the early successional habitat that was created on the north end. Not only did reproductive success rise above the level necessary to increase the local population, adult birds from other breeding sites moved into the Maryland breeding population.

By 1996, the Maryland plover population had risen to 60 pair and has remained relatively constant suggesting that it may be at capacity for the current available habitat. For the past 12 years, reproductive success has averaged 1.4 chicks per pair, which is the calculated rate necessary to maintain the population. This stability has been maintained despite an average nest loss rate of 37%, due primarily to tidal events (the risk of living low), and depredation by crows, gulls and fox.

In 2003, the Army Corps of Engineers, in partnership with the National Park Service and others, began the first of a two-phase process of restoring the sediment flow around the inlet to the north end of Assateague Island. The initial phase included the installation of a beach and berm filet along the north end to prevent additional erosion prior to the sediment influx that will result from the second long-term project phase. The design of this filet was modeled to permit normal tidal events to impact the habitat at a level similar to the remainder of the island. In concept, the Restoration project has 'made the island whole' in terms of the long-shore sediment budget, and the NPS now returns to its strategy of allowing future tidal events to dictate the surficial features of the island.

At present, the north end of Assateague Island is the only section of the Maryland coastline that is physically functioning in a manner close to natural conditions. The response by early successional species like the Piping plover since the 1992 event provides an indication that the habitat is in transition. The future of species and communities that capitalize on beach migration is expected to change with the periodicity of future tidal events. Maturation of some 'young' habitats will also yield other communities that are also valuable, but not well represented in the Coastal Bays. Newly emergent fresh and saltmarsh wetlands along the North End provide evidence to this evolution.

The southern 12 miles of the Maryland coastline on Assateague still possesses topographic features and vegetated communities that reflect past stabilization efforts. But with time, coastal storms will manipulate this section of the island, resulting is changes to the island in addition to the Chincoteague Bay itself. It is not improbable that inlet formation will be part of that change and the influence to the Coastal Bays could be rather remarkable.

Foraging habitat in the Coastal Bays watershed for the Piping plover occurs bayward of the dune line on Assateague. So, here is to an indicator species, the Piping plover. Our prognosticator of change and all that it offers to the health of the Coastal Bays system.

Status of piping plovers

Efforts to study the Piping plover (*Charadrius melodus*) in Maryland began in 1986, the year that the shorebird was listed as a Threatened species. After 5 years, research results were sobering. With the breeding population dropping from 25 to 14 pair and an annual reproductive success rate 30% below the level necessary to maintain the population, survival estimate models predicted that local (Maryland) extinction could occur by 2016, short of some major changes to coastal habitat.

Plovers on Delmarva are most successful when the breeding pairs have access to moist, unvegetated shoreline habitat supporting abundant invertebrate prey. They appear to prefer areas such as inlets that are free of hardened stabilization structures and overwash fans laid across barrier islands and spits. Unfortunately, coastal Maryland has been managed with a heavy hand for development since the 1950's. The construction of jetties and continuous dunes has eliminated most potential plover breeding habitat along the Coastal Bays.

The National Park Service began to manage the southern 36 kilometers (22 miles) of the Maryland coastline in 1965, and stopped most stabilization activities on Assateague Island in the mid-1970s. Their management strategy has been to allow natural tidal events to redefine the island's previously constructed primary dune line and ultimately return the land to a more natural barrier beach.

To date, the only portion of Assateague Island that has received sufficient tidal influence for cross-island overwash has been a 9.5 km (6 mile) section just south of the Ocean City Inlet, adjacent to the Sinepuxent Bay. An initial pair of tidal events occurred during the winter of 1991/92, but it took a summer or two for the invertebrate population to fully colonize the new early-successional habitat. Leg-band sightings showed that in addition to local breeding birds, plovers were immigrating to Assateague from other breeding sites. After three additional seasons, the Assateague breeding population had tripled to 60 pair, plus 10-15 non-breeding birds.

For the past eight breeding seasons, the Piping plover breeding population has remained stable at around 60 pairs (and additional non-breeding birds). Although difficult to evaluate, it is possible that the population is at capacity for the available conditions. (Table 8.9.1).

Summary

Despite a second tidal event in 1998 that helped maintain the early succession habitat in certain areas, the maturing of the landscape has been constant. The early successional overwash habitat along northern Assateague Island is evolving to other barrier island habitats: dune fields, ephemeral wetlands, shrub thickets and saltmarsh. Those communities have been observed to host a range of wetland and upland faunas that have been absent over the past decade. This normal evolution displaces plovers, due to the loss of open habitat necessary for nesting and foraging. In fact, for the past two seasons the breeding plover population has been under stress as evidenced by aggression between courting, nesting and brood-rearing plovers.

In an ideal world, adjacent barrier beaches would also be managed for sea-level rise and island migration. Tidal events would create new inlets or early-succession beach and plovers would migrate to fill these new niches. The ragged boundary of guts and marsh islands along the eastern edge of the Coastal Bays are reminders of the historic influence of overwash events. We should expect history to eventually repeat itself.

In time, the remaining portion of Assateague will be rearranged by the energy of tides and winds. It is not improbable that inlet formation will be part of that change and the influence to the Coastal Bays could be rather remarkable. Until that change occurs, we may see Maryland's Piping Plover population under peril. Only time and the winds will tell.

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Table 8.9.1 Breeding Population and Historic Success of Piping Plover on Assateague Island National Seashore, MD 1986-2003.

Year	*Maryland Breeding pairs*	*Nests hatched (% success)*	*Chicks fledged (% success)*	*Chicks fledged per pair*	*Southern Recovery Unit Pairs*
1986	**17**	**14 (61%)**	**18 (47%)**	**1.1**	**158**
1987	**23**	**16 (48%)**	**27 (59%)**	**1.2**	**160**
1988	**25**	**13 (38%)**	**13 (35%)**	**0.5**	**171**
1989	**20**	**11 (41%)**	**18 (50%)**	**0.9**	**199**
1990	**14**	**8 (40%)**	**11 (44%)**	**0.8**	**201**
1991	**18**	**14 (70%)**	**7 (15%)**	**0.4**	**194**
1992	**24**	**14 (47%)**	**24 (56%)**	**1**	**172**
1993	**20**	**11 (37%)**	**34 (87%)**	**1.7**	**181**
1994	**32**	**31 (74%)**	**77 (74%)**	**2.4**	**186**
1995	**44**	**41 (91%)**	**76 (51%)**	**1.7**	**217**
1996	**61**	**50 (69%)**	**91 (53%)**	**1.5**	**189**
1997	**60**	**54 (54%)**	**60 (34%)**	**1**	**204**
1998	**56**	**46 (65%)**	**73 (50%)**	**1.3**	**203**
1999	**58**	**50 (68%)**	**63 (43%)**	**1.1**	**182**
2000	**60**	**46 (48%)**	**48 (32%)**	**0.8**	**183**
2001	**60**	**41 (41%)**	**55 (39%)**	**0.9**	**208**
2002	**60**	**57 (90%)**	**111 (54%)**	**1.9**	**209**
2003	**59**	**48 (67%)**	**92 (57%)**	**1.6**	

Chapter 8.9

Aquatic non-native and invasive species in the Maryland Coastal Bays

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Abstract

Exotic or non-native species can become invasive when they are introduced in areas where they lack predators or other natural controls on their populations. They can take over food or habitat used by native species and thus displace the native species. A variety of exotic species have been found in the Coastal Bays, particularly near man- made structures. Three inter-tidal, marine invasive species have been documented: the Asian Shore Crab, (*Hemigrapsus sanguineus)*, the European Green Crab, (*Carcinus maenas)*, and Deadman's Fingers Macroalgae, (*Codium fragile)*. All were found predominantly in association with rocky, riprap substratum, and five of eight Bays hosted one of more of these species. No invasive species were documented in Newport Bay (one site surveyed), Assawoman Bay (five sites) or Little Assawoman Bay in Delaware (three sites).

Introduction

Non-native species and invasive species are exotic species that when introduced to an area may grow uncontrollably, thus displacing native species and decreasing habitat value for native plants and animals. Currently, phragmites, mute swans, nutria, green crabs and the Pacific Shore crab are known to exist in the Coastal Bays.

This report summarizes the findings of "Assessment of Invasive Species in the Coastal Bays of Delaware and Maryland," a project supported by a grant from the Maryland Coastal Bays and the Delaware's Center for the Inland Bays National Estuary Programs. The goal of this project was to provide a comprehensive assessment of invasive species in the Coastal Bays of Maryland and the Inland Bays of Delaware. In all, 59 intertidal surveys have been conducted at 38 separate sites (Figure 8.9.1). From October 2002 through December 2003, surveys were conducted of the intertidal shoreline in all eight coastal and inland bays: Assawoman, Isle of Wight, Sinepuxent, Newport, and Chincoteague Bays in Maryland, and Rehoboth, Indian River and Little Assawoman Bays in Delaware. Sites throughout the bays were chosen to include ecological reserves and state parks as well as invasion "hot spots" such as disturbed / dredge areas, marinas, inlets and other potential points of entry.

Management Objective: Reduce and control invasive/ exotic species.

Indicator: Percent non-native species

Analyses

At each site, species present were recorded (collecting specimens for laboratory identification and vouchers), temperature, salinity, shoreline and substratum type, and vegetation type. Each site was located with GPS coordinates and photographed to document habitat type. Close-up photographs were taken to show invasive or otherwise notable species in their natural habitat.

Status of intertidal invasive species

Three intertidal, marine invasive species have been documented: the Asian shore crab, *Hemigrapsus sanguineus* (Figure 8.9.2), the European Green Crab *Carcinus maenas* (Figure 8.9.3), and Deadman's Fingers Algae, *Codium fragile* (Figure 8.9.4). All were found dominantly in association with rocky, riprap substratum, and 5 of 8 bays hosted one of more of these species (Table 8.9.1). No invasive species were documented in Newport (1 site surveyed), Assawoman (5 sites) and Little Assawoman Bays (3 sites).

Table 8.9.1 Percent occurrence of three intertidal, marine invasive species at survey locations.

		% with indicated invasive species		
Location	**% with riprap shoreline sites**	Asian shore crab *Hemigrapsus sanguineus*	Deadman's Fingers Algae *Codium fragile*	European Green Crab *Carcinus maenas*
Survey sites (n=38)	55% (21/38)	42% (16/38)	24% (9/38)	13% (5/38)
Bays (n=8)	100%	63% (5/8)	50% (4/8)	25% (2/8)

Hemigrapsus sanguineus and *Codium fragile* (Figures 8.9.2 and 8.9.3) were found broadly throughout the area, while the distribution of *Carcinus maenas* (Figure 8.9.4) was more restricted to the Indian River and Ocean City inlet areas.

Summary

None of the three intertidal species was found in association with vegetated, salt marsh shoreline. In contrast, artificial rock or riprap shoreline commonly hosted one or more of the three invasive species. Invasive species were found in all seasons sampled. MD DNR Fisheries have also found juvenile green crabs associated with Fucus (Rockweed) growing on the water edges of marshes near the inlet. While our survey did not quantify abundance, *Hemigrapsus sanguineus* was clearly the most abundant and **ecologically** dominant species in rocky intertidal in the Coastal Bays.

The abundance and dominance of *Hemigrapsus sanguineus* in the rocky intertidal zone of the Coastal Bays (Figure 57b) suggest that further research is warranted. Studies could include patterns of seasonal abundance, size-frequency and biomass; rock size preference (or other substratum characteristics); and seasonality, mechanism and rate of colonization of new riprap installations. Consideration should also be given to the benthic community effects of *Hemigrapsus sanguineus* as it appears to be superior space competitor and an effective predator. Fisherman at Indian River Inlet reportedly use locally collected *Hemigrapsus sanguineus* as bait for tautog fishing at the inlet jetties, and the possibilities of establishing and promoting a bait fishery for Asian shore crabs should be investigated.

Both *Codium fragile* and *Carcinus maenas* were less common and more restricted to the lower intertidal region. Especially large *Codium fragile* were found in on ropes in Chincoteague Bay marina. The most effective means of collecting *Carcinus maenas* for laboratory experiments has been subtidal traps (Epifanio 2003). We found green crabs only near the two major inlets, at Indian River Inlet and near Ocean City. Together these observations suggest that additional survey work for subtidal invasive species, especially near boat docks and marinas, should be considered.

References

Epifanio, C. 2003. University of Delaware, College of Marine Studies, Lewes, DE. Personal communication.

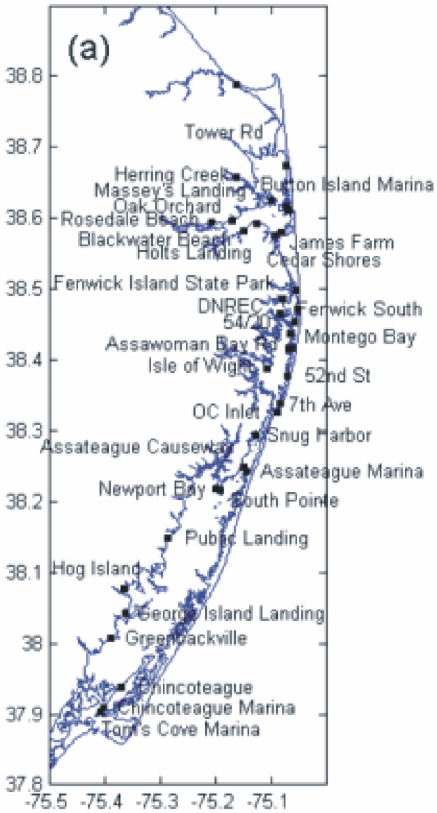

Figure 8.9.1: Coastline of Delaware and Maryland showing coastal and inland bays with locations of 38 intertidal survey sites.

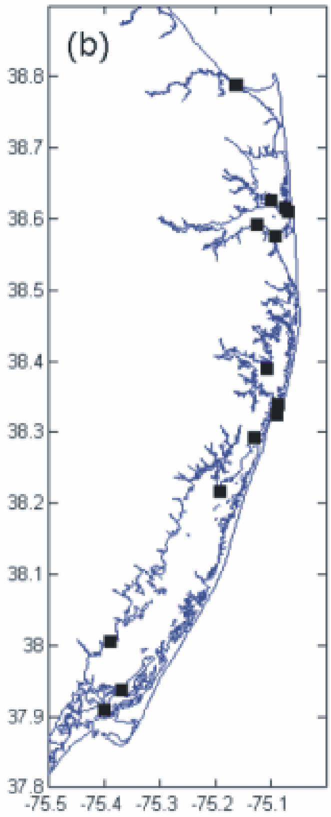

Figure 8.9.2. Occurrence of the Asian shore crab, *Hemigrapsus sanguineus.*

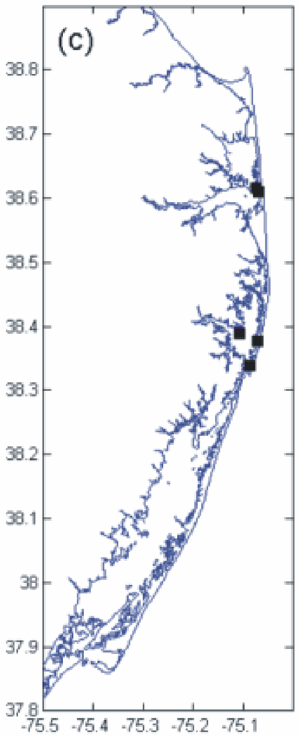

Figure 8.9.3. Occurrence of the European green crab, *Carcinus maenas.*

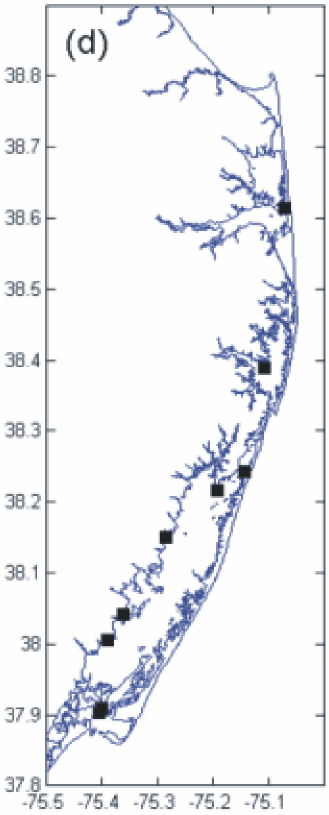

Figure 8.9.4. Occurrence of deadman's fingers macrolgae, *Codium fragile*.

Section 9: Summary

Introduction

The following chapter brings together many of the elements presented in this report as an Ecosystem Health Index. This index is a method of assessing the overall health of the Coastal Bays, as well as the individual bay segments. Overall ranking of the bay segments placed them in the following order from best to worst overall health: Sinepuxent Bay, Chincoteague Bay, Assawoman Bay, Isle of Wight Bay, Newport Bay, and the St. Martin River. Strengths and weaknesses of the Ecosystem Health Index are discussed as well.

Chapter 9.1   Coastal Bays Ecosystem Health Index: Bringing it all together

Coastal Bays Ecosystem Health Index:
Bringing it all together

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Introduction

So, how are the Coastal Bays doing environmentally?

This simplistic, but commonly asked, question drove the research that went into each chapter in this document. 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 seagrass acreage, others had definitive downward trends, such as forage fish abundance. Narrowing the geographic scope, 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. These broad results begin to answer the question, but may be considered too broad and too convenient for some inquiries.

The purpose of this document was to provide a comprehensive assessment of ecosystem health for use in driving policy decisions. Though the information contained in each chapter and the status of the various indicators contained within 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, and as a first attempt at answering the question posed at the beginning of this section, an estuarine health index was developed based on the results of this report. This index also serves as a summary to the document as a whole.

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. Three water quality indicators (water quality index, brown tides, macroalgae), three living resources indicators (benthic index, hard clam abundance, sediment toxicity), and three habitat indicators (seagrass area, wetland area, natural shoreline) 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 nine 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.

Brown tide
Maximum brown tide range within each segment for the three-year period between 2001 and 2003 was used (see Chapter 7.1, especially Figure 7.1.1).

Macroalgae
Maximum total macroalgal biomass per square meter (g/m^2) within each segment over the period 1999 through 2003 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 6.3.1 (see Chapter 6.3).

Benthic index
The within-segment mean MAIA benthic index score (2000-2001) was used (see Chapter 8.5).

Hard clams
The average of the number of clams per station within each segment for 2003 was used (see Chapter 8.4, especially Figure 8.4.2).

Sediment toxicity
The mean Apparent Effect Threshold (AET) value, averaged within segment, was used. The mean AET values were not reported, but they were used to develop Figure 5.2.2 (see Chapter 5.2).

Seagrass area
The total seagrass acreage within each segment was used, based on the 2002 survey data (see Chapter 6.1). These values were then converted to a percentage of bottom area for each segment.

Wetland area

Raw within-segment National Wetland Inventory (NWI) acreages from the 1988 through 1989 survey were used (see Chapter 6.4). 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 (see below).

Natural shoreline

Raw total natural shoreline miles for each segment from the 1989 survey were used (see Chapter 6.5). These values were then converted to a percentage of total shoreline miles taken from the same survey.

Results

Within-segment means served as raw index values for each segment (Table S.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 and one were scaled accordingly (Table S.2). The set of scaled values was then averaged within segment, resulting in a final estuarine health index value for each segment (Table S.2).

Table S.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]	Brown tide[2]	Macroalgae[3]	Benthic index[4]	Hard clams[5]	Sediment toxicity[6]	Seagrass area[7]	Wetland area[8]	Natural shoreline[9]
Assawoman Bay	0.33	35-200	102.35	3.35	0.16	12.04	8	45	72
Isle of Wight Bay	0.53	35-200	250.95	3.07	0.28	10.65	5	16	35
St. Martin River	0.33	35-200	392.7	2.18	0.04	19.01	1	16	52
Sinepuxent Bay	0.85	35-200	46.86	3.5	0.32	10.42	36	61	81
Newport Bay	0.35	>200	10.39	3.4	0.14	13.01	4	23	96
Chincoteague Bay	0.74	>200	315.95	3.6	0.27	8.09	32	45	98

[1]Water quality index ranges from 0 (no reference criteria met) to 1 (all reference criteria met). [2]Cell count per liter. [3]Grams/m^2. [4]Ranges from 1(poor) to 5(good). [5]Clams/m^2. [6]Threshold values based on a range of toxicants from various studies. [7]Percent of segment covered. [8]Percent of watershed. [9]Percent of total shoreline.

Table S.2: Scaled values for each indicator by segment, based on raw values in Table S.1. Final index values are also shown. The same color-coding applies to this table.

Indicator / Segment	WQI[1]	Brown tide	Macroalgae	Benthic index	Hard clams	Sediment toxicity	Seagrass area	Wetland area	Natural shoreline	**Estuarine Health Index**
Assawoman Bay	0.0	1.0	0.8	0.8	0.4	0.6	0.2	0.6	0.6	**0.6**
Isle of Wight Bay	0.4	1.0	0.4	0.6	0.9	0.8	0.1	0.0	0.0	**0.4**
St. Martin River	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	**0.1**
Sinepuxent Bay	1.0	1.0	0.9	0.9	1.0	0.8	1.0	1.0	0.7	**0.9**
Newport Bay	0.0	0.0	1.0	0.9	0.4	0.5	0.1	0.2	1.0	**0.4**
Chincoteague Bay	0.8	0.0	0.2	1.0	0.8	1.0	0.9	0.6	1.0	**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 S.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 northern bay segments demonstrating lower indeces than southern bay segments. These indeces, based on raw values, are summarized in Table S.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 relatively high levels of brown tide and macroalgae. High seagrass area and natural shoreline mileage and low sediment toxicity values 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.

The third-ranked segment was Assawoman Bay with an index value of 0.6. A low water quality index (identical to last-ranked St. Martin River), 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 very low sediment toxicity and brown tide values, and mid-range habitat indicators (except seagrass coverage).

Ranking fourth, at 0.4, Isle of Wight Bay demonstrated reasonable water quality, but low values in all three 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 (shoreline, wetlands, and seagrass area).

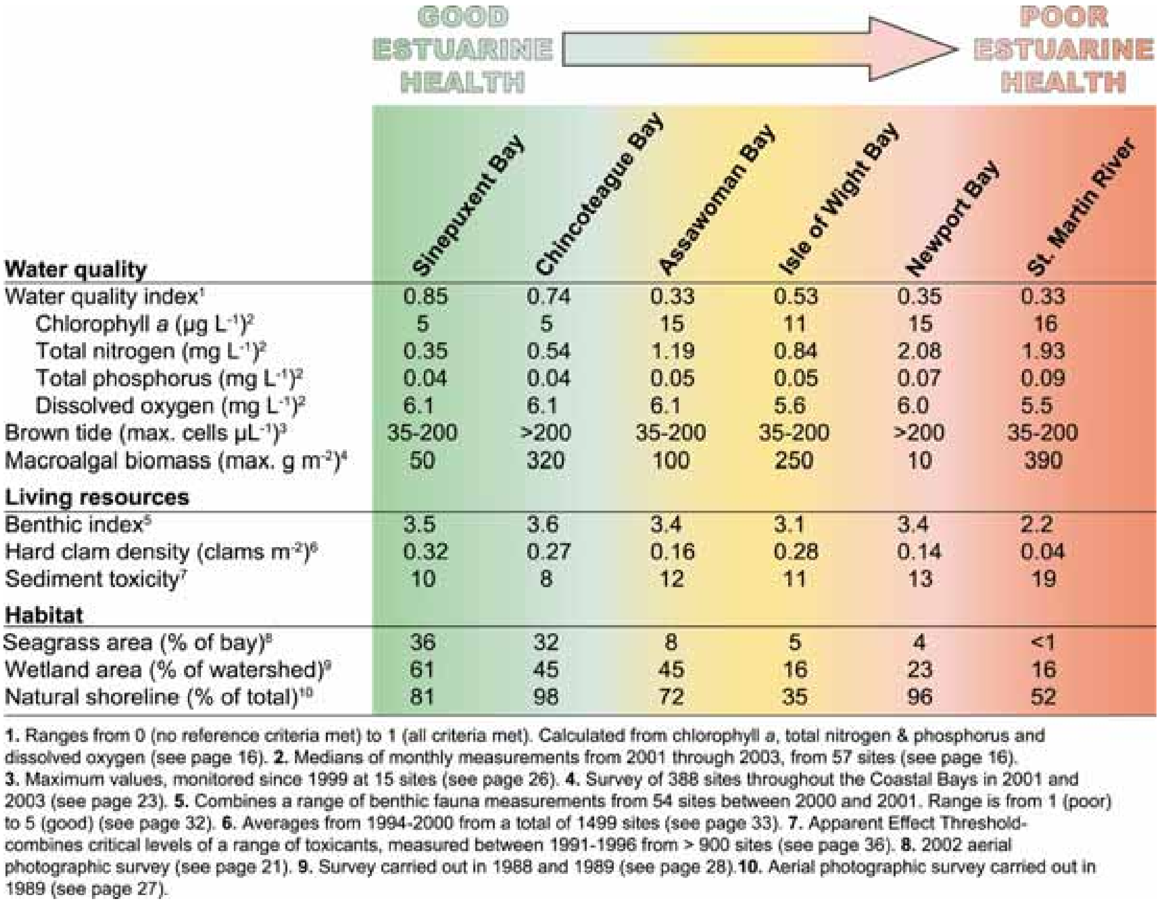
Newport Bay ranked fifth among the Coastal Bays segments due to very poor water quality. Newport Bay suffers from chronically high phytoplankton concentrations (as evidenced by chlorophyll *a* values) and brown tide blooms, reduced hard clam densities, high sediment toxicity and very little seagrass 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.

Ranking last, the St. Martin River had the lowest index values for nearly all indicators. This river had the highest phytoplankton and phosphorus concentrations, as well as the lowest dissolved oxygen concentrations (see breakout in Table S.3). All three living resources indicators ranked the lowest in this river, and seagrass and wetlands were nearly non-existant. 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. This has 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 this was most likely unavoidable. Another issue is the uneven weight given to some indicators. For instance, because only categories and not true values were used, there were only two possible scaled values for brown tide (Table S.2). Thus, at least with those segments receiving a scaled value of 1.0, an underestimation of the impact of brown tide may be present. Of course, simply using mean raw values for brown tide concentration as with the other indicators could alleviate this. Another possible solution is the development of a ranking system based on something other than relative values (i.e., comparison to reference estuaries).

Table S.3: Estuarine health index results, based on raw values. Note that the four components of the water quality index are separated in this representation.



	Sinepuxent Bay	Chincoteague Bay	Assawoman Bay	Isle of Wight Bay	Newport Bay	St. Martin River
Water quality						
Water quality index[1]	0.85	0.74	0.33	0.53	0.35	0.33
Chlorophyll *a* ($\mu g\ L^{-1}$)[2]	5	5	15	11	15	16
Total nitrogen ($mg\ L^{-1}$)[2]	0.35	0.54	1.19	0.84	2.08	1.93
Total phosphorus ($mg\ L^{-1}$)[2]	0.04	0.04	0.05	0.05	0.07	0.09
Dissolved oxygen ($mg\ L^{-1}$)[2]	6.1	6.1	6.1	5.6	6.0	5.5
Brown tide (max. cells μL^{-1})[3]	35-200	>200	35-200	35-200	>200	35-200
Macroalgal biomass (max. $g\ m^{-2}$)[4]	50	320	100	250	10	390
Living resources						
Benthic index[5]	3.5	3.6	3.4	3.1	3.4	2.2
Hard clam density (clams m^{-2})[6]	0.32	0.27	0.16	0.28	0.14	0.04
Sediment toxicity[7]	10	8	12	11	13	19
Habitat						
Seagrass area (% of bay)[8]	36	32	8	5	4	<1
Wetland area (% of watershed)[9]	61	45	45	16	23	16
Natural shoreline (% of total)[10]	81	98	72	35	96	52

1. Ranges from 0 (no reference criteria met) to 1 (all criteria met). Calculated from chlorophyll *a*, total nitrogen & phosphorus and dissolved oxygen (see page 16). **2.** Medians of monthly measurements from 2001 through 2003, from 57 sites (see page 16). **3.** Maximum values, monitored since 1999 at 15 sites (see page 26). **4.** Survey of 388 sites throughout the Coastal Bays in 2001 and 2003 (see page 23). **5.** Combines a range of benthic fauna measurements from 54 sites between 2000 and 2001. Range is from 1 (poor) to 5 (good) (see page 32). **6.** Averages from 1994-2000 from a total of 1499 sites (see page 33). **7.** Apparent Effect Threshold-combines critical levels of a range of toxicants, measured between 1991-1996 from > 900 sites (see page 36). **8.** 2002 aerial photographic survey (see page 21). **9.** Survey carried out in 1988 and 1989 (see page 28).**10.** Aerial photographic survey carried out in 1989 (see page 27).

Appendix A: Molluscs of The Maryland Coastal Bays

A species list of Molluscs collected by the Maryland DNR Shellfish Program Molluscan Inventory (1993-96) and subsequent surveys

Taxonomic nomenclature, references, and common names follow Turgeon et al. 1998. Recent synonyms are in brackets. Notes: d - taxa represented by dead specimens only; nr – new record, not previously reported from Maryland Coastal Bays though within known geographic range; re – new record, geographic range extension; fin - additional species collected by the DNR Coastal Bays Finfish Investigation Project (redundant taxa and offshore species not included).

Gastropoda

Scientific Name	Common Name	Notes
Acteocina [=Cylichnella] bidentata (d'Orbigny, 1841)	two-tooth barrel-bubble	re
Acteocina canaliculata (Say, 1826)	channeled barrel-bubble	
Anguispira alternata (Say, 1816)	flamed tigersnail	nr
Astyris [= Mitrella] lunata (Say, 1826)	lunar dovesnail	
Costoanachis [=Anachis] avara (Say, 1822)	greedy dovesnail	
Bittiolum alternatum (Say, 1822)		
Bittiolum varium (Pfeiffer, 1840)	grass cerith	nr
Boonea impressa (Say, 1822)	impressed odostome	d
Busycon carica (Gmelin, 1791)	knobbed whelk	fin
Busycotypus canaliculatus (Linné, 1758)	channeled whelk	
Cerithiopsis greenii (C.B.Adams, 1839)		
Cerithiopsis emersonii (C.B.Adams, 1839)		d
Columbellidae		
Corambe [=Doridella] obscura (Verrill, 1870)	obscure corambe	
Crepidula convexa Say, 1822	convex slippersnail	
Crepidula fornicata (Linné, 1758)	common Atlantic slippersnail	
Crepidula plana Say, 1822	eastern white slippersnail	
Diodora cayenensis (Lamarck, 1822)	cayenne keyhole limpet	d
Doriopsilla pharpa Marcus, 1961	lemon drop	nr
Doris verrucosa Linne, 1758	sponge slug	nr
Epitonium multistriatum (Say, 1826)	many-ribbed wentletrap	

Gastropoda (cont'd)

Epitonium rupicola (Kurtz, 1860)	brown-band wentletrap	
Epitonium sp.		
Eupleura caudata (Say, 1822)	thick-lip drill	
Haminoe solitaria (Say, 1822)	solitary glassy-bubble	nr
Hydrobia truncata [=totteni,=minuta] (Vanatta, 1924)	minute hydrobe	nr
Kurtziella cerina (Kurtz & Stimpson, 1851)		
Littorina irrorata (Say, 1822)	marsh periwinkle	fin
Marshallora [=Triphora] nigrocincta (C.B. Adams, 1839)	black-lined triphora	
Melampus bidentatus Say, 1822	eastern melampus	
Melanella sarsi [=intermedia] Bush, 1909		
Nassarius [=Ilyanassa] obsoleta (Say, 1822)	eastern mudsnail	
Nassarius trivittatus (Say, 1822)	threeline mudsnail	
Nassarius vibex (Say, 1822)	bruised nassa	
Neverita [=Polinices] duplicata (Say, 1822)	shark eye	
Odostomia pocahontasae Henderson & Bartsch, 1914		
Pyramidella crenulata (Holmes, 1860)		re
Pyrgocythara plicosa (C.B.Adams, 1850)	plicate mangelia	nr
Rictaxis [= Acteon] punctostriatus (C.B.Adams, 1840)	pitted baby-bubble	nr
Seila adamsii (H.C.Lea, 1845)		nr
Stramonita [=Thais] haemastoma floridana (Conrad, 1837)	Florida rocksnail	d
Turbonilla interrupta (Totten, 1835)		nr
Turbonilla powhatani Henderson & Bartsch, 1914		d
Turbonilla sp. B		
Turridae sp. A		d
Turridae sp. B		
Urosalpinx cinerea (Say, 1822)	Atlantic oyster drill	

Bivalvia

Aligena elevata (Stimpson, 1851)	eastern aligena	nr
Anadara ovalis (Bruguiére, 1789)	blood ark	
Anadara transversa (Say, 1822)	transverse ark	
Anomia simplex d'Orbigny, 1842	common jingle	
Argopecten irradians (Lamarck, 1819)	bay scallop	
Barnea truncata (Say, 1822)	Atlantic mud-piddock	
Crassostrea virginica (Gmelin, 1791)	eastern oyster	
Cumingia tellinoides (Conrad, 1831)	tellin semele	nr
Cyclinella tenuis (Récluz, 1852)	thin cyclinella	re
Cyrtopleura costata (Linné, 1758)	angelwing	
Donax variabilis Say, 1822	variable coquina	
Ensis directus Conrad, 1843	Atlantic jackknife	
Gemma gemma (Totten, 1834)	amethyst gemclam	
Geukensia demissa (Dillwyn, 1817)	ribbed-mussel	
Ischadium recurvum (Rafinesque, 1820)	hooked mussel	
Laevicardium mortoni (Conrad, 1830)	yellow eggcockle	d
Lyonsia hyalina Conrad, 1831	glassy lyonsia	
Macoma balthica (Linné, 1758)	Baltic macoma	
Macoma cf. *phenax* Dall, 1900	cheating macoma	nr
Macoma tenta (Say, 1834)	elongate macoma	
Mercenaria mercenaria (Linné, 1758)	northern quahog	
Mulinia lateralis (Say, 1822)	dwarf surfclam	
Mya arenaria Linné, 1758	softshell	d
Mysella planulata (Stimpson, 1851)	plate mysella	nr
Mytilus edulis Linné, 1758	blue mussel	

Bivalvia (cont’d)

Noetia ponderosa (Say, 1822)	ponderous ark	
Nucula proxima Say, 1822	Atlantic nutclam	
Petricola pholadiformis (Lamarck, 1818)	false angelwing	
Pitar morrhuana Linsley, 1848	false quahog	
Raeta plicatella (Lamarck, 1818)	channeled duckclam	
Solemya velum Say, 1822	Atlantic awningclam	
Solen viridis Say, 1822	green jackknife	
Spisula solidissima (Dillwyn, 1817)	Atlantic surfclam	
Tagelus divisus (Spengler, 1794)	purple tagelus	
Tagelus plebeius (Lightfoot, 1786)	stout tagelus	
Tellina agilis Stimpson, 1857	northern dwarf-tellin	
Yoldia limatula (Say, 1831)	file yoldia	fin

Cephalopoda

Loligo pealeii (Lesueur, 1821)	longfin inshore squid	fin
Lolliguncula brevis (de Blainville, 1823)	Atlantic brief squid	fin

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Appendix B: Finfish of the Maryland Coastal Bays

A finfish catch and siting list - Coastal Bays and adjacent Atlantic Ocean (1986 – 2004). Maryland Coastal Bays Fisheries Investigation program (Maryland DNR).

-- Versar Code No.

1. Odontaspididae - Sand Tiger family
    * Odontaspis taurus - Sand Tiger-------------------2464

2. Carcharhinidae - Requiem Shark family
    * Negaprion brevirostris - Lemon Shark ------------2465
    * Carcharhinus milberti - Sandbar Shark -----------2466
    * Mustelus canis - Smooth Dogfish Shark -----------2467
    * Carcharhinus obscurus - Dusky Shark -------------3271

3. Lamnidae - Mackerel Shark family
    *Cetorhinus maximus - Basking Shark ---------------2468

4. Sphyrnidae - Hammerhead Shark family
    * Sphyrna zygaena - Smooth Hammerhead Shark ---2469

5. Squalidae - Spiny Dogfish family
    * Squalus acanthias - Spiny Dogfish ---------------2470

6. Squatinidae - Angel Shark family
    * Squatina dumerili - Atlantic Angel Shark --------3259

7. Rajidae - Skate family
    * Raja eglanteria - Clearnose Skate ---------------2471

8. Dasyatidae - Stingray family
    * Dasyatis americana - Southern Stingray ----------2472
    * Gymnura micrura - Smooth Butterfly Ray ----------2473

9. Myliobatidae - Eagle Ray family
    * Myliobatis freminvillei - Bullnose Ray ----------2474
    * Rhinoptera bonasus - Cownose Ray ----------------0014

10. Clupeidae - Herring family
    * Clupea harengus - Atlantic Herring --------------0012
    * Alosa aestivalis - Blueback Herring -------------0004
    * Alosa pseudoharengus - Alewife ------------------0006
    * Opisthonema oglinum - Atlantic Thread Herring ---0017

- * Brevoortia tyrannus - Atlantic Menhaden ---------0008
- * Dorosoma cepedianum - Gizzard Shad --------------0009

11. Engraulidae - Anchovy family
    - * Anchoa mitchilli - Bay Anchovy ------------------0025
    - * Anchoa hepsetus - Striped Anchovy ---------------0024

12. Anguillidae - Freshwater Eel family
    - * Anguilla rostrata - American Eel ----------------0021

13. Congridae - Conger Eel family
    - * Conger oceanicus - Conger Eel -------------------0020

14. Synodontidae - Lizardfish family
    - * Synodus foetens - Inshore Lizardfish ------------0022

15. Cyprinodontidae - Killifish family
    - * Cyprinodon variegatus - Sheepshead Minnow -------0052
    - * Lucania parva - Rainwater Killifish -------------0056
    - * Fundulus heteroclitus - Mummichog ---------------0054
    - * Fundulus majalis - Striped Killifish ------------0055
    - * Fundulus diaphanus - Banded Killifish -----------0053
    - * Fundulus luciae - Spotfin Killifish -------------2475

16. Exocoetidae - Flyingfish family
    - * Hyporhamphus unifasciatus - Halfbeak ------------0049

17. Belonidae - Needlefish family
    - * Strongylura marina - Atlantic Needlefish --------0050

18. Gadidae - Codfish family
    - * Urophycis regia - Spotted Hake ------------------0159
    - * Urophycis chuss - Red Hake ----------------------2476
    - * Pollachius virens - Pollock ---------------------3109
    - * Merluccius bilinearis - Silver Hake -------------3258

19. Pleuronectidae - Righteye Flounder family
    - * Pseudopleuronectes americanus - Winter Flounder -0097

20. Bothidae - Lefteye Flounder family
    - * Paralichthys dentatus - Summer Flounder ---------0096
    - * Paralichthys oblongus - Fourspot Flounder -------2477
    - * Scophthalmus aquosus - Sand Dab -----------------2478
    - * Etropus microstomus - Smallmouth Flounder -------2479

21. Soleidae - Sole family
* Trinectes maculatus - Hogchoker -----------------0098

22. Cynoglossidae - Tonguefish family
* Symphusus plagiusa - Blackcheek Tonguefish ------2193

23. Antherinidae - Silverside family
* Menidia menidia - Atlantic Silverside -----------0062
* Menidia beryllina - Inland Silverside -----------0061
* Membras martinica - Rough Silverside ------------0060

24. Mugilidae - Mullet family
* Mugil cephalus - Striped Mullet -----------------0158
* Mugil curema - White Mullet -------------------2088

25. Sphyraenidae - Barracuda family
* Sphyraena borealis - Northern Sennet ------------2480
* Sphyraena barracuda - Great Barracuda -----------2481

26. Gasterosteidae - Stickleback family
* Apeltes quadracus - Fourspine Stickleback -------0064
* Gasterosteus aculeatus - Threespine Stickleback -2414

27. Syngnathidae - Pipefish & Seahorse family
* Syngnathus fuscus - Northern Pipefish -----------0067
* Syngnathus floridae - Dusky Pipefish ------------0066
* Hippocampus erectus - Lined Seahorse ------------0065

28. Tetraodontidae - Puffer family
* Spheroides maculatus - Northern Puffer ----------0099
* Spheroides nephelus - Southern Puffer -----------2482

29. Chaetodontidae - Butterflyfish family
* Chaetodon ocellatus - Spotfin Butterflyfish -----2483

30. Fistulariidae - Cornetfish family
* Fistularia tabacaria - Bluespotted Cornetfish ---2484

31. Stromateidae - Butterfish family
* Peprilus triacanthus - Butterfish --------------0093
* Peprilus alepidotus - Harvestfish ---------------0092

32. Carangidae - Jack family

    * Caranx hippos - Crevalle Jack -------------------1218
    * Caranx latus - Horse-Eye Jack -------------------2485
    * Selene setapinnus - Atlantic Moonfish -----------2486
    * Selene vomer - Lookdown -------------------------2487
    * Caranx hippos - Blue Runner ---------------------0077
    * Trachinotus falcatus - Permit -------------------2488
    * Selar crumenophthalmus - Big Eye Scad -----------2489
    * Trachurus lathami - Rough Scad ------------------3261
    * Trachinotus carolinus - Round Pompano -----------2996

33. Pomatomidae - Bluefish family
    * Pomatomus saltatrix - Bluefish ------------------0076

34. Percichthyidae - Temperate Bass family
    * Morone saxatilis - Striped Bass -----------------0001
    * Morone americana - White Perch ------------------0002

35. Serranidae - Sea Bass family
    * Centropristis striata - Black Sea Bass ----------0069
    * Mycteroperca microlepis - Gag -------------------2490

36. Haemulidae - Grunt family
    * Orthopristis chrysoptera - Pigfish --------------2491

37. Sparidae - Porgy family
    * Stenotomus chrysops - Scup (Porgy) --------------2492
    * Lagodon rhomboides - Pinfish --------------------2493
    * Diplodus holbrooki - Spottail Pinfish -----------3266

38. Sciaenidae - Drum family
    * Cynoscion regalis - Weakfish --------------------0081
    * Menticirrhus saxatilis - Northern Kingfish ------0083
    * Leiostomus xanthurus - Spot ---------------------0082
    * Micropogonias undulatus - Croaker ---------------0084
    * Pogonias cromis - Black Drum --------------------2494
    * Bairdiella chrysoura - Silver Perch -------------0079
    * Sciaenops ocellatus - Red Drum ------------------0085
    * Cynoscion nebulosus - Spotted Seatrout ----------0080

39. Triglidae - Searobin family
    * Prionotus evolans - Striped Searobin ------------0095
    * Prionotus carolinus -Northern Searobin ----------0094

40. Labridae - Wrasse family

* Tautoga onitis - Tautog -------------------------0087
* Tautogolabrus adspersus - Cunner ----------------2495

41. Gobiidae - Goby family
    * Gobiosoma bosci - Naked Goby --------------------0090
    * Gobiosoma ginsburgi - Seaboard Goby -------------0105
    * Microgobius thalassinus - Green Goby ------------2496

42. Ammodytidae - Sand Lance family
    * Ammodytes americanus - American Sand Lance ------2497

43. Uranoscopidae - Stargazer family
    * Astroscopus guttatus - Northern Stargazer -------2498

44. Blennidae - Blenny family
    * Chasmodes bosquianus - Striped Blenny -----------0089
    * Hypsoblennius hentzi - Feather Blenny -----------2499

45. Ophidiidae - Cusk Eel family
    * Ophidion marginatum - Striped Cusk Eel ----------2500

46. Batrachoididae - Toadfish family
    * Opsanus tau - Oyster Toadfish -------------------0046

47. Gobiesocidae - Clingfish family
    * Gobiesox strumosus - Skilletfish ----------------0047

48. Balistidae - Leatherjacket family
    * Balistes capriscus - Gray Triggerfish -----------2501
    * Monacanthus hispidus - Planehead Filefish -------2502
    * Aluterus schoepfi - Orange Filefish -------------0091

49. Diodontidae - Porcupinefish family
    * Chilomycterus schoepfi - Striped Burrfish -------0100

50. Lophiidae - Anglerfish family
    * Lophius americanus - Goosefish ------------------2503

51. Priacanthidae - Bigeye family
    * Priacanthus arenatus - Bigeye -------------------2504
    * Pristigenys alta - Short Bigeye -----------------2505

52. Molidae - Mola family

* Mola mola - Ocean Sunfish ----------------------0213

53. Elopidae - Tarpon family
* Elops saurus - Ladyfish -------------------------2506

54. Cyprinidae - Minnow & Carp family
* Notemigonus chrysoleucas - Golden Shiner --------0031
* Notropus cornutis - Common Shiner ---------------0032
* Cyprinus carpio - Carp --------------------------0029

55. Centrarchidae - Sunfish family
* Lepomis gibbosus - Pumpkinseed ------------------0072
* Lepomis macrochirus - Bluegill ------------------0202
* Enneacanthus gloriosus - Blue Spotted Sunfish ---2095
* Pomoxis nigromaculatus Black Crappie ----------0179

56. Ictaluridae Catfish family
* Ictalurus nebulosus Brown Bullhead ------------0042

57. Umbridae - Mudminnow family
* Umbra pygmaea - Eastern Mudminnow ---------------0149

58. Esocidae - Pike family
* Esox americanus - Redfin Pickerel ---------------2191

59. Ephippidae - Spadefish family
* Chaetodipterus faber - Spadefish ----------------2561

60. Tetraodontidae - Puffer family
* Lagocephalus laevigatus - Smooth Puffer ---------2995
* Sphoeroides maculatus - Northern Puffer ---------0099
* Sphoeroides nephelus - Southern Puffer ----------2482

61. Lutjanidae - Snapper family
* Lutjanus campechanus - Red Snapper --------------2997
* Lutjanus sp.   ? Gray Snapper --------------3303

62. Gerreidae - Mojarra family
* Eucinostomus argenteus - Spotfin Mojarra --------2559

63. Scombridae - Mackerel & Tuna family
* Scomberomorus cavalla - King Mackerel -----------3098
* Scomberomorus maculatus - Spanish Mackerel ------3095

64. Rachycentridae - Cobia family
* Rachycentron canadum - Cobia --------------------3265

65. Poeciliidae - Livebearer family
* Gambusia affinis - Mosquitofish -----------------0059

66. Cryptacanthodidae - Wrymouth family
* Cryptacanthodes maculatus - Wrymouth ------------3270

67. Ostraciontidae Boxfish family
* Lactophrys trigonus Common Trunkfish -----------3106

68. Mulidae Goatfish family
* Upeneus parvus ? Dwarf Goatfish -----------------3260