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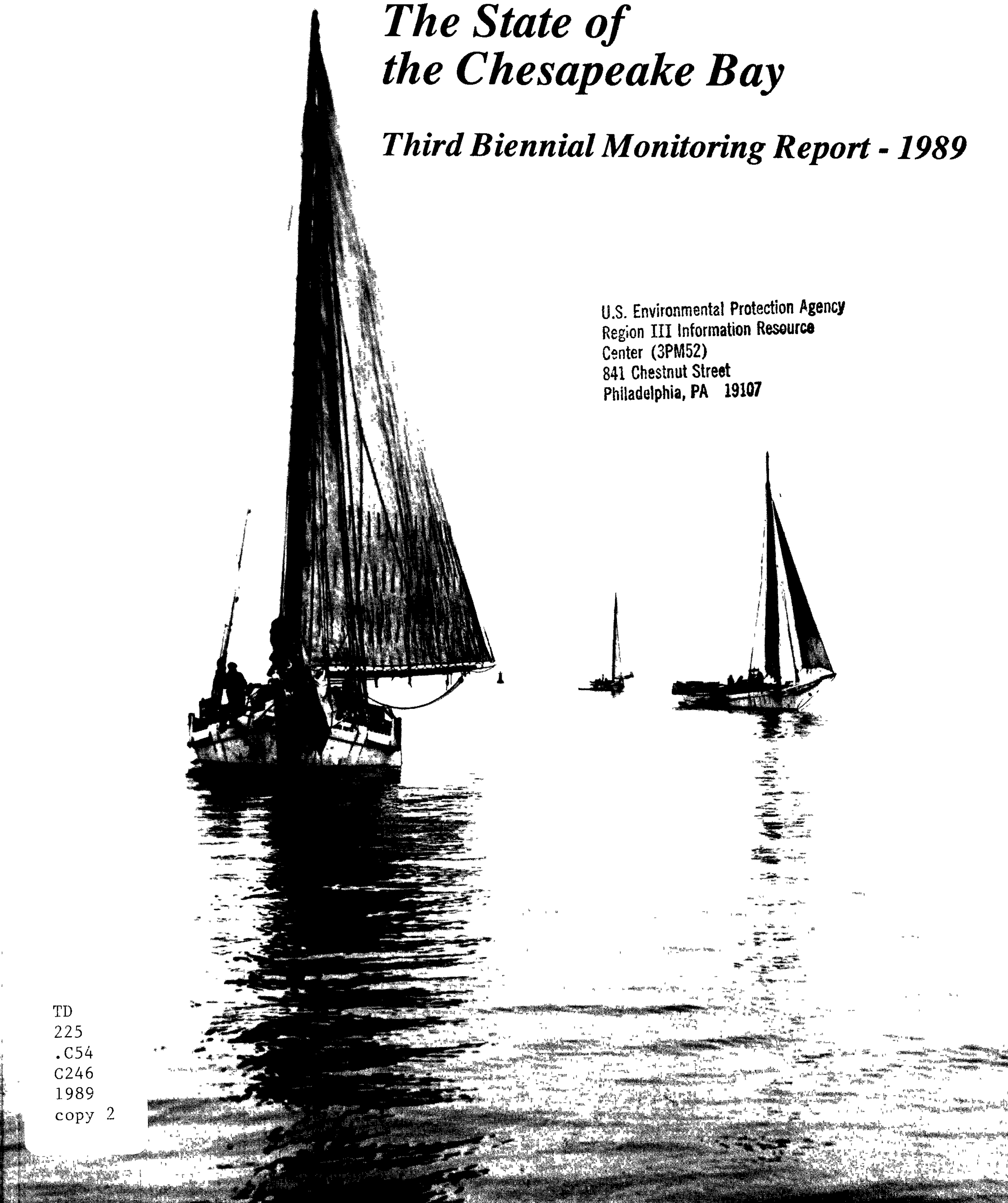
The State of the Chesapeake Bay

Third Biennial Monitoring Report - 1989



Foreword

1989 STATE OF THE BAY

The Participants

This report was produced by the Data Analysis Workgroup of the Chesapeake Bay Program's Monitoring Subcommittee: R. Magnien, Chair, R. Alden, R. Batiuk, M. Burch, C. Heywood, F. Hoffman and J. Mihursky.

Executive Editor/ Designer/Graphic Artist: Nina Fisher, CSC

Authors: Eric Barth
Richard Batiuk
Mary Jo Brown
Michael Burch
Diana Domotor
Nina Fisher
Frederick Hoffman
Jerrald Hollowell
Linda Hurley
Steve Jordan
George Krantz
Robert Magnien
Bruce Michael
Joseph Mihursky
Narendra Panday
James Uphoff
Gail Walton

Photos: M.E. Warren

Illustrators: A.J. Lippson, Elaine Kasmer, Sue Armstrong

MONITORING—Webster defines it: " to watch, observe, or check especially for a special purpose." For the Chesapeake Bay Program, the definition of monitoring takes on additional dimensions—the long-term process of collecting critical environmental data throughout a 66,500 square mile ecosystem. Hundreds of individuals—scientists, managers, technicians and citizens—from a multitude of agencies and institutions are involved in the analysis and presentation of the information for management of this vast watershed and tidal system. Insights into the state of the Bay and the future course of management action are the culmination of this process.

This complex array of people, stations, and data is yielding the information necessary to support wise management decisions for Bay restoration. With time, trends in water quality and shifts in plant and animal populations have begun to evolve. Only now, with the trend information emerging, can we begin to distinguish natural variability from man-induced changes—basic information, yet critical to shape decisions for the Bay.

We know the ultimate goal—a balanced, productive estuary—and signs of recovery are beginning to unfold. For the first time since Bay restoration started, we have the substantial, high quality monitoring data needed to move forward into the next phase. Monitoring must not stop here. The growing base of monitoring information will provide the means to continuously refine and improve our stewardship of the Bay. There is no better means to accurately and objectively evaluate what the Bay once was, where it now stands, and what path it is traveling towards the future.

Chesapeake Bay Program Monitoring Subcommittee

Monitoring Subcommittee

Robert Perciasepe, Chair, MD Dept. of the Environment
Lee Zeni, Vice-Chair, Interstate Comm. on the Potomac River Basin
Raymond Alden, Old Dominion Univ.
Richard Batiuk, U.S. Environmental Protection Agency
Robert Bielo, Susqehanna River Basin Comm.
Mark Chittenden, VA Institute of Marine Science
Steve Funderburk, U.S. Fish & Wildlife Service
Carlton Heywood, Interstate Comm. on the Potomac River Basin
Frederick Hoffman, VA Water Control Board
Steve Jordan, MD Dept. of Natural Resources
Hamid Karimi, DC Environmental Control Div.
Dennis Lynch, U.S. Geological Survey
Robert Magnien, MD Dept. of the Environment
Samuel McCoy, National Oceanic and Atmospheric Adm.
Joseph Mihursky, Chesapeake Biological Lab
Sheila Myers, Metropolitan Washington Council of Governments
Bruce Neilson, VA Institute of Marine Science
Robert Pace, US Army Corps of Engineers
James Sanders, Benedict Estuarine Research Lab
Dwayne Womer, PA Dept. of Envirornmental Resources

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On the Cover

The front cover photograph was taken by M.E. Warren in 1956 as he spent the day with the Tidewater Fisheries patrol. The watermen are dredging oysters under power just off Love Point at the north tip of Kent Island. The three turn-of-the-century skipjacks capture the Bay in one of its most classic poses. Mr. Warren graciously donated his photographs for use in this report. (Archive # MdHR G 1890-25-12,664-20)

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Monitoring the Bay Ecosystem

Like the Hopi Indian word portraying life out of balance—koyannisqatsi— the Chesapeake Bay is a system out of balance. Those early benefactors of the Bay, the Indians and colonists, found a balanced, yet dynamic, Chesapeake. Storms, seasonal warming and cooling of the waters, rising and falling levels of dissolved oxygen and fluctuating levels of salinity and nutrients dictated the daily, seasonal and yearly rhythms of the Bay. Fish migrated in and out of its waters sensing subtle temperature changes while waterfowl foraged in the rich Bay marshes and aquatic grasses upon return from their northern breeding grounds. Algae flourished with the coming of spring but were held in check by the millions of filter feeders, such as oysters, that feasted on these tiny floating plants. The Bay was constantly changing yet maintained a delicately balanced stance.

As more and more people inhabited the Bay region, they cut the forests and fished the waters more intently. Large ships began to ply the waterways, homes crowded along her shores and the Bay became a receptacle for the wastes of our growing society. Through the years, the Bay played an increasing number of commercial and recreational roles. It was remarkably resilient in the early years of exploitation—the bounties it could offer seemed endless. Eventually, the conflicting roles began to take their toll. Harvests of finfish and shellfish plummeted, the once flourishing submerged sea grasses withered in the turbid, nutrient-laden waters and toxic "hotspots" have raised fears for the health of the Bay and humans alike.

The degradation has not gone unnoticed. Since the mid-1900s, scientists and managers have attempted to unravel the complexities of the Bay's decline. By 1984, the work had not only increased but there began a concerted effort on the part of the Bay states and jurisdictions to pool resources and jointly tackle the multitude of problems. In an attempt to explain the stresses facing the Chesapeake, recent research has focused on the variety of interactions among the physical, chemical and biological components of the Bay. A detailed picture of the energy pathways moving through the system, from the sun's energy to the high-level consumers, is now emerging. Scientists have also enhanced their understanding of how man's activities interfere with the natural flow of energy. This expanded understanding allows us to focus management and regulatory efforts on Bay restoration while increasing the yield of harvestable resources.

One means to assess how much living matter is produced in the Bay and what pathways this "energy" follows is to track the amount of carbon in different groups of organisms. Carbon is one of the basic chemical "building blocks" of life. Figure 1 shows the annual weight of carbon produced in the mesohaline portion of the Bay. This production is divided into plants (primary producers), zooplankton (small floating animals), bottom-dwelling animals (benthos) and fish within a representative slice of the Bay's middle zone. Even under natural conditions, only a fraction of the plant production eventually reaches the economically important finfish and shellfish. The task of managers is to restore the Chesapeake to a balanced ecosystem in which as much of this energy as possible is funneled into important and useful biological yields— oysters, striped bass and waterfowl, among others. In the Bay's current condition, much of the plant production does not reach these higher levels but ends up decomposing on the Bay bottom, robbing the water of much needed oxygen.

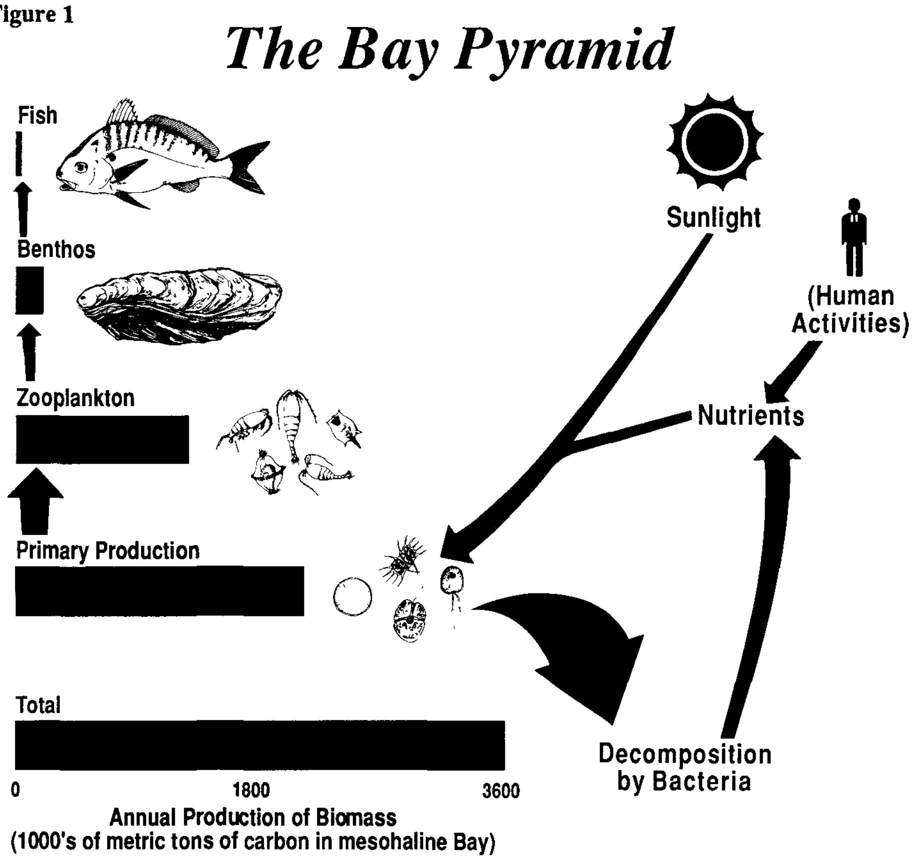
Mirroring the complexities of the Chesapeake Bay ecosystem, monitoring is an intricate yet systematic process designed to reveal the dynamics of the Bay. Beginning in the outer reaches of the watershed, researchers track and measure the sources of nutrients and other pollutants. Within the Bay, itself, specialists monitor a variety of factors to provide a comprehensive diagnosis of the Bay's health. As data collection continues, scientists unravel the technical details and translate the information into terms meaningful to managers and legislators who in turn implement specific actions to remedy the Bay's

ills. Citizens, informed of the monitoring program findings, work within the process by collecting supplemental data for some of the programs. Their involvement is critical: ultimately, it is the citizens of the Bay region who will pass judgment on the value of the Bay and what we should spend to protect it.

Using Monitoring Information

Monitoring plays a key role in guiding the Bay's restoration, making it imperative that the information collected through the monitoring programs be promptly and appropriately interpreted and used. The first State of the Bay report in 1985 introduced the newly initiated Chesapeake Bay Monitoring Program. The second report gave a preliminary picture of the Bay portrayed by the first two years of monitoring data while elaborating on the variety of projects under the auspices of the Monitoring Program. In this, the third report on the state of the Bay, case studies depict the linkage between long-term environmental monitoring and Bay management, providing an up-to-date diagnosis of the Bay's health.

Figure 1



Using these case studies, the report demonstrates the progress and successes in using monitoring information for specific management decisions that have been made or will soon be required. Some of these accounts rely on data collected before many of the recent programs started; they show clearly the importance of a long-term record. In these instances, we can definitively state from where we've come, where we are and where we're likely to go in the future. Given many of the uncertainties that still exist in our understanding of the estuary, these case studies teach important lessons. Unqualified successes documented by monitoring programs in areas such as the Potomac River, give us the confidence to move forward with similar management approaches in other areas.

The prognosis for continued use of monitoring information to support the Bay restoration is excellent. Since 1984, the gaps in existing monitoring programs have been closed. The governors of the Bay states, the mayor of Washington D.C. and the federal government have committed to continued coordination of the baywide monitoring programs.

Monitoring spans the spectrum from the policymakers to the individual taking samples in the Bay. We are approaching a milestone in the latest Bay Agreement where all relevant monitoring information will be used to scrutinize and reevaluate the current baywide nutrient reduction strategy by 1991. This is a challenge that will test the limits of the existing programs and interjurisdictional coordination but is certain to set a more confident course for our management of the Bay.

The Problems

Excess Nutrients: The Bay is suffering from too much of a good thing. An overabundance of nutrients, particularly nitrogen and phosphorus, kicks off a chain reaction in which phytoplankton bloom, die off, sink and are decomposed by bacteria. During decomposition, the bacteria can use up much or all of the dissolved oxygen, making it uninhabitable for most animals.

Sediments: *Geologic processes generally take place on a lengthy time scale.* When man's activities speed up processes such as erosion of the shoreline and land, problems inevitably result. Suspended sediment clouds the water and decreases the amount of light able to reach aquatic grasses. As the sediment settles, it may smother non-mobile shellfish, prevent oyster spat from setting and alter the type of animal that can live on the Bay bottom.

Toxics: A toxic substance is any material which is harmful or fatal to organisms. Scientists have found high concentrations of numerous toxic metals and organic compounds in the Bay water and sediment, particularly in industrialized areas such as the Patapsco and Elizabeth rivers. *These compounds can cause chronic or lethal* effects in the animals and plants.

Low Dissolved Oxygen: As a consequence of nutrient overenrichment, the Bay's deep bottom waters become depleted of dissolved oxygen (DO) each summer. In the most severe areas, no DO exists—a condition known as anoxia. Without oxygen, almost all organisms are driven away or die. Even low DO conditions—hypoxia—severely stress Bay animals.

Habitat Loss: As the Bay region has undergone development over the past centuries, substantial habitat has been lost to the plow, bulldozer and backhoe. While many habitats *have been lost outright, others have been* severely modified by the indirect impact of these acitivities. Sediment running off the land has clogged wetlands, turbidity and nutrient overenrichment have destroyed SAV and accelerated erosion has destroyed shoreline habitat.

Monitoring Programs

Like analysts diligently tracking the daily fluctuations and long-term trends of the stock market, Bay scientists monitor the Chesapeake Bay. Routine collection and analysis of water samples provide information on short and long-term changes in water quality while the status of the supporting members of the estuarine food web—plankton, benthic organisms and aquatic grasses—are monitored as the primary indicators of the Bay's biological health. Building on a data base reaching back to the 1950s, monitoring of the Bay's finfish and shellfish populations provides the information needed to ensure wise management of existing living resources—the ultimate measure of our success in revitalizing the Bay. Monitoring serves not only to assess the current "state of the Bay" and long-term trends, but also to help better understand its dynamics in response to pollution reduction.

In 1984, state and federal agencies initiated a coordinated monitoring program in the Chesapeake Bay mainstem and its tidal tributaries. Integrated with this water quality network (50 mainstem, 40 Virginia tributary and 57 Maryland tributary stations) are plankton, benthos and sediment sampling at some of these stations. The Chesapeake Bay Monitoring Program has since expanded to include monitoring activities in the District of Columbia, other living resource monitoring programs, and monitoring of non-tidal Bay tributaries. This section provides an overview of the Monitoring Program and related Bay basin monitoring programs.

In August 1989, the Bay Program's Monitoring Subcommittee published the "Chesapeake Bay Basin Monitoring Program Atlas," a document containing summary descriptions of ongoing, long-term environmental monitoring programs within the watershed. The number and diversity of monitoring programs described in the atlas attest to the wealth of information being generated for management purposes. Yet, the sheer number of programs emphasizes the need to integrate across jurisdictional boundaries—in essence, to treat the Chesapeake as a whole.

Physical Processes Monitoring

Precipitation has a tremendous influence on the Bay as a direct (atmospheric) and indirect (runoff) source of nutrients and toxicants. Through the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Network, researchers sample 268 stations over the Bay basin for key meteorological parameters. Scientists use precipitation and climate information for computer modeling and to explain the relationship between land use and nonpoint source pollutants.

Water Quality Monitoring

If the mainstem Bay is the lower trunk of a large tree, then the freshwater streams and rivers are the vast network of roots sustaining the tree. Water and nutrients move through the roots eventually finding their way into the trunk. Monitoring in the "roots," extending into New York, West Virginia and Delaware, provides valuable infor-mation on their contribution to the Bay's overall water quality.

Closer to the Bay, state monitoring networks in Pennsylvania, Maryland and Virginia track water quality trends. In addition, the states concentrate intensive nonpoint source sampling of nutrient and pesticide loads in selected watersheds. By monitoring water quality within a watershed, managers can determine the contribution of pollutants from all upstream sources. Monitoring water quality where the free-flowing river meets tidal waters provides a measure of the total upstream load of nutrients and toxicants moving into the tidal waters. Baseflow and storms are both monitored to characterize pollutant loadings from point sources, groundwater and nonpoint sources.

In all the Bay basin states, the U.S. Geological Survey (USGS) maintains networks of water quality monitoring and streamflow gaging stations as part of a national program initiated in the 1890s. The USGS, Maryland and Virginia cooperatively monitor water quality, nutrients and metals at the fall line. Technicians collect baseflow and storm samples on the Susquehanna, Patuxent, Potomac and Choptank rivers in Maryland and on the James, Appomattox, Pamunkey, Mattaponi and Rappahannock rivers in Virginia.

All the states monitor municipal and industrial point source dischargers within their Bay basin jurisdictions. Self-monitoring (performed by the

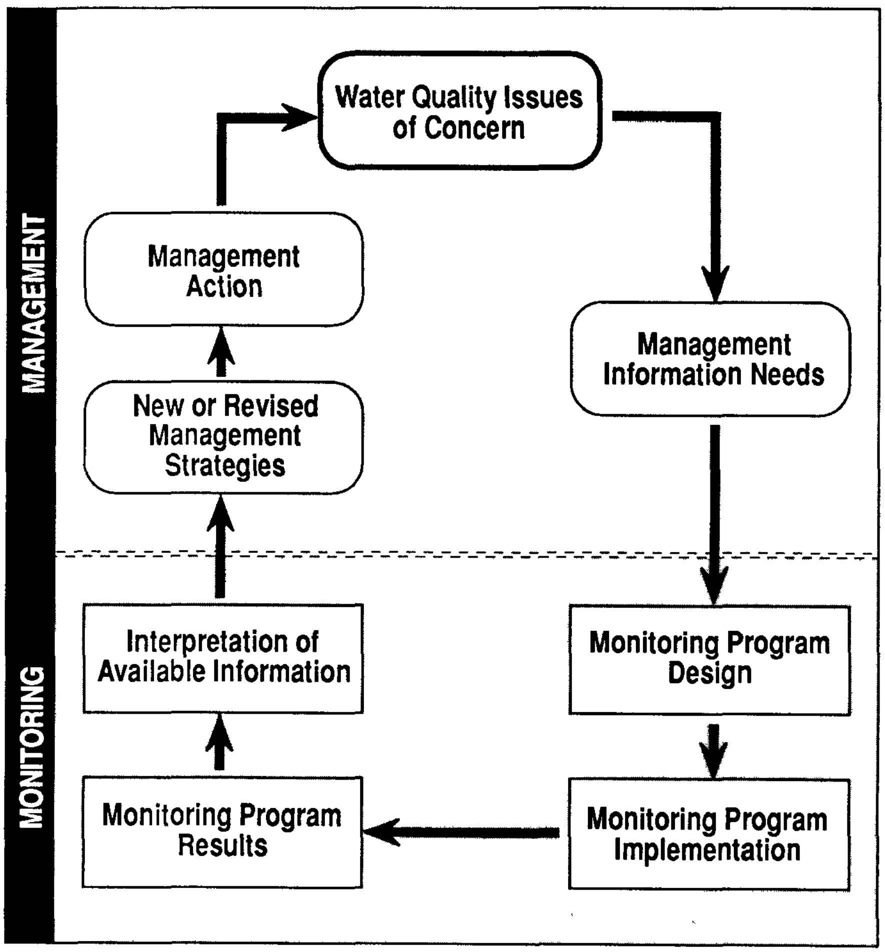


Figure 2. Sequence of steps linking management and monitoring. When the loop between the water quality issues that led to the development of the monitoring program and the resultant management actions closes, the program has realized its goal.

discharger) and compliance monitoring (performed by the states) provide managers with detailed estimates of point source toxicants and nutrient loads.

As nutrients and suspended sediments enter the tidal Chesapeake Bay, state monitoring programs measure their impact on estuarine water quality. Closely coordinated with fall line and nontidal tributary monitoring, these programs identify the sources of pollutants, the fate of these pollutants and their impact on habitat quality. Reduction targets can then be established based on the source and characteristics of individual pollutants.

Through joint state and federal funding, Maryland and Virginia have monitored water quality at 50 stations throughout the Bay's mainstem since 1984. At the same time, these states have sampled a network of tidal tributary water quality stations. Water quality monitoring of the Potomac and Anacostia rivers within the District of Columbia has continued since a similar network was established in 1979. Comparable field, analytic and data management techniques allow the compilation of these data on a centralized computer database in Annapolis, Maryland. Other important data used in the Bay analyses include the basinwide Citizen Monitoring Program which brings volunteers into the monitoring of Bay water quality. Engineers, farmers, retirees, students and others sample the Conestoga, Patuxent, Choptank, James and other rivers on a weekly basis.

Living Resources Monitoring

As Bay water quality improves, beneficial changes in the species forming the food web base will signal a return to a dynamically balanced estuary capable of sustaining healthy plants and animals. Maryland, Virginia and the District of Columbia all monitor the composition, abundance and distribution of phytoplankton, zooplankton and benthic organisms at a subset of the Bay water quality monitoring stations.

Aquatic grasses provide a strong link between improved water quality and recovery of the Bay's living resources. Given their importance as food and habitat, they are a key barometer of Bay health. The baywide aerial survey program, initiated in 1978, has documented recent increases in the distribution and abundance of submerged aquatic vegetation (SAV). Field surveys and water quality monitoring in SAV beds complement the aerial survey program, using state and university personnel as well as watermen and citizen volunteers.

At the higher levels of the food web, monitoring becomes progressively more difficult. A variety of factors combine to influence the health and status of the finfish and shellfish—harvest pressure, eutrophication, food availability, climatic events and habitat change. The finfish and shellfish monitoring programs are evolving to provide the understanding of fish populations needed for management.

Examples of Other Monitoring Programs Within the Bay Basin

Acid Deposition - Maryland Acid Precipitation Monitoring Program

Air Quality - New York Air Quality Monitoring Program

Groundwater - West Virginia Observation Well Network

Habitat Monitoring - Maryland Striped Bass Habitat Monitoring Program

Lake Monitoring - Virginia Lake Monitoring Program

Nonpoint Source Monitoring - Virginia Nomini Creek Watershed Monitoring Program

Radiology - Pennsylvania Radiological Monitoring Program

Special Coordinated Programs - Coordinated Anacostia Monitoring Program

Special Toxics Monitoring - Virginia Kepone Finfish Monitoring Program

Utility Supported - Philadelphia Electric Co., Susquehanna River Water Quality Monitoring Program

Under a program initiated in 1939, Maryland monitors oyster spat and condition at bars in the northern Bay each fall. Virginia conducts spring and fall surveys of oyster bars, spatfall counts and disease surveys at selected stations throughout the lower Bay. As oyster numbers continue to decline under harvest pressures and increased prevalence of disease, data are needed to manage the state oyster repletion program and regulate annual harvests.

As recreational and commercial harvests of blue crabs increase, impacts on the crab populations will continue to be monitored. Maryland monitors the seasonal abundance of adult blue crabs while Virginia tracks the abundance of larvae and juveniles.

Maryland, Virginia and the District of Columbia monitor the abundance and distribution of finfish through seine and trawl survey programs. Managers use this information is used to oversee current fishery stocks. They also use the long-term data records, along with other information, to evaluate the effectiveness of habitat restoration initiatives and to target pollution abatement programs.

In Maryland, surveys of nearshore fish populations in the upper Bay and the Choptank, Nanticoke, and Potomac rivers began in 1954. Scientists survey juvenile river herring populations in the upper tidal tributaries from June to September. American shad populations have been monitored in the upper Bay since 1980. Maryland's Adult Striped Bass Survey includes sampling at over 60 non-fixed stations throughout the northern Chesapeake Bay.

The District of Columbia's two finfish programs survey anadromous and resident finfish on the Potomac and Anacostia rivers. Under Virginia's juvenile finfish survey program, the state has assessed the current status and long-term trends of Virginia's juvenile finfish populations in the James, York and Rappahannock rivers since 1954. In these same rivers, the state has also used beach seine surveys to evaluate juvenile striped bass populations. Juvenile herring and shad populations are surveyed at stations located on the Mattaponi and Pamunkey rivers to monitor year class strength.

Given the importance of the Chesapeake region as part of the Atlantic Flyway for migratory waterfowl as well as the Bay's abundant habitats for resident song, wading and shorebirds, there is a strong focus on monitoring bird populations. The U.S. Fish and Wildlife Service (USFWS) estimates populations through its annual Chesapeake Bay midwinter waterfowl survey. Using volunteers, the National Audubon Society conducts a December bird count throughout the basin as part of a nationwide program and USFWS volunteers annually survey waterfowl breeding. Pennsylvania and Maryland also administer annual waterfowl breeding surveys. Maryland and Virginia participate annually in a bald eagle survey and Virginia regularly monitors its populations of ospreys and colonial birds.

Toxicants Monitoring

Contaminants in sediments and animals pose hazards to other Bay animals and man as these substances migrate through the food web. In their tidal waters, Maryland and Virginia analyze sediments every 3-5 years for contaminant levels. State and federal programs ensure that the Bay's shellfish and finfish are safe for consumption.

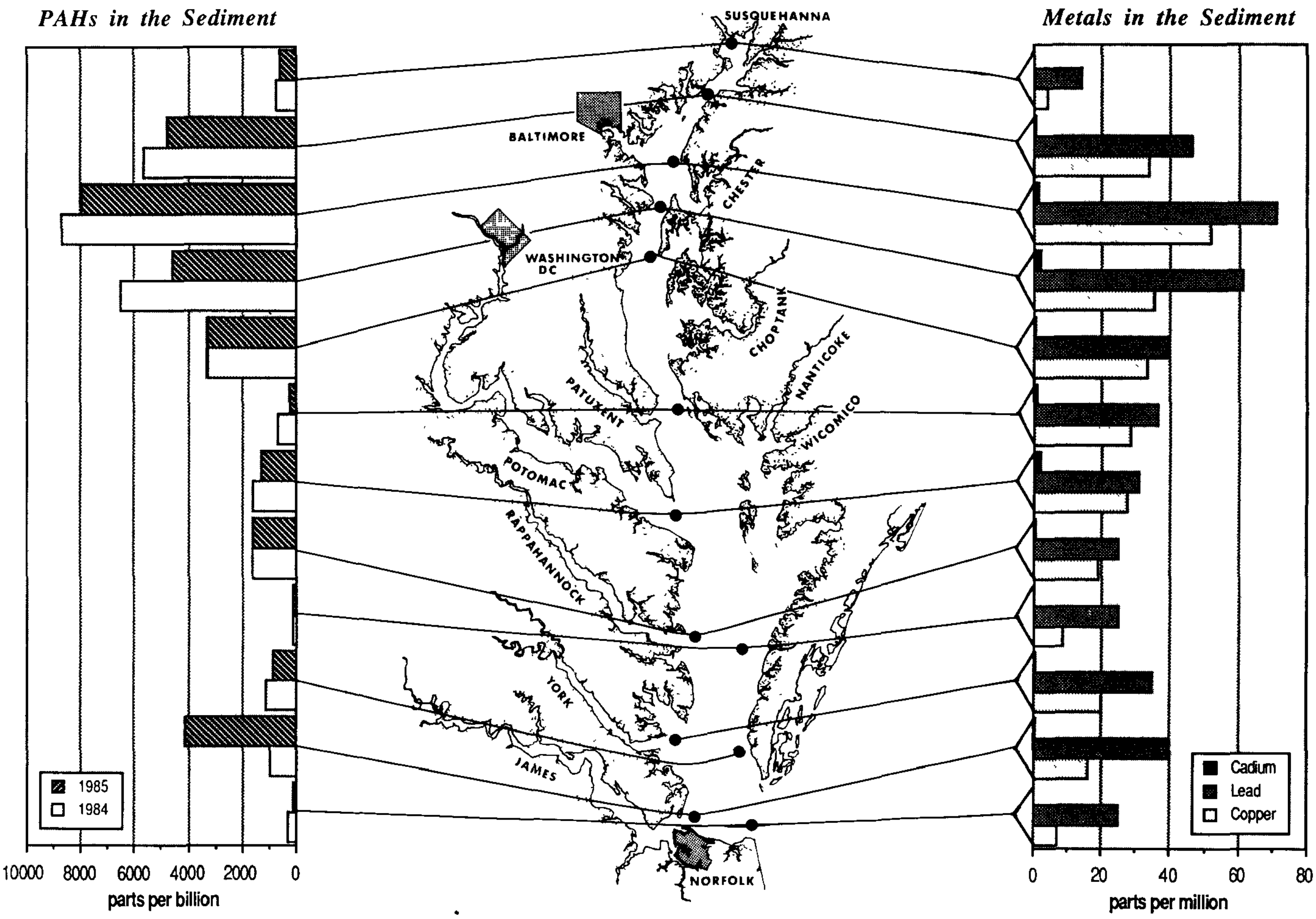
Under the EPA's national contaminant monitoring program, finfish tissue contaminant levels are monitored in Pennsylvania, Maryland, the District of Columbia, Virginia and West Virginia. The USFWS maintains stations on the Susquehanna, Potomac and James rivers under its national pesticide monitoring program. NOAA also monitors shellfish and finfish tissue contaminants as part of its National Status and Trends Program. Scientists use these data to compare the status of the coasts and estuaries bordering the nation.

How is the Bay Doing?

The most commonly asked question of anybody working on the restoration of the Chesapeake Bay is apparently simple—"How is the Bay doing?" It's not an easy question. The Bay is suffering from a variety of maladies. The answer depends on the specific problem. Some remarkable achievements have been made on many of the problems—yet there is much left to accomplish.

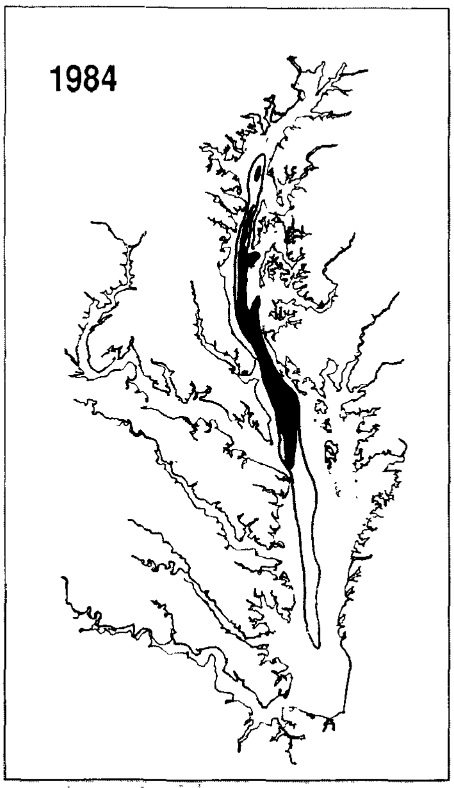
Pictures have a way of translating information in ways that words cannot. The following section relies primarily on illustrations to spell out the many states of the Chesapeake Bay.

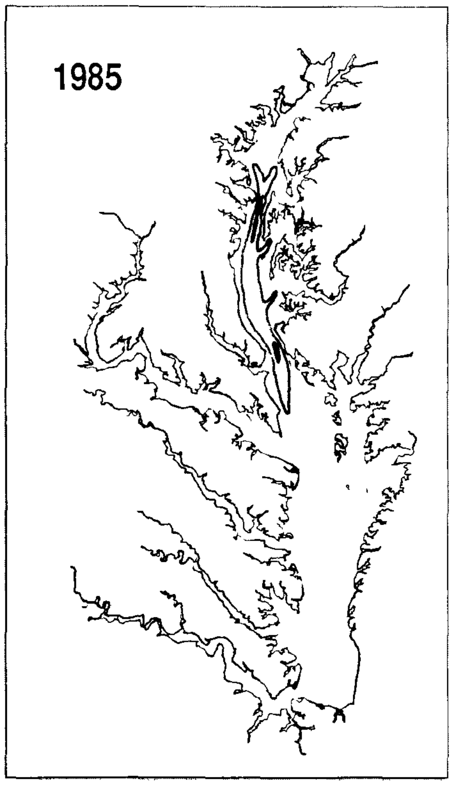
The Unseen Contaminants

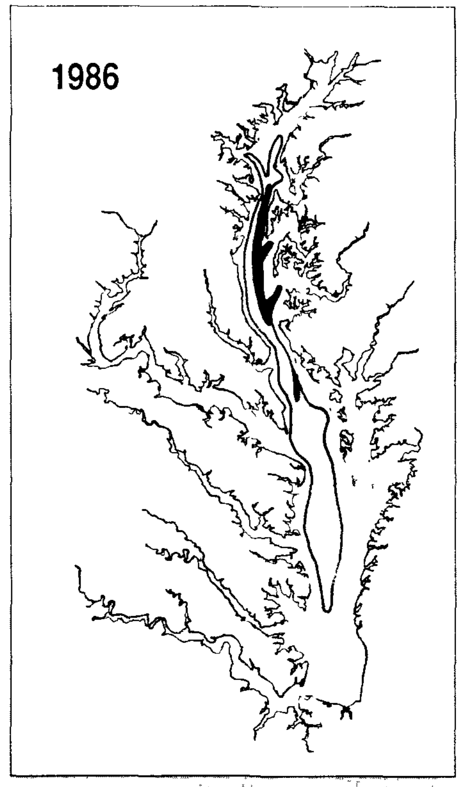


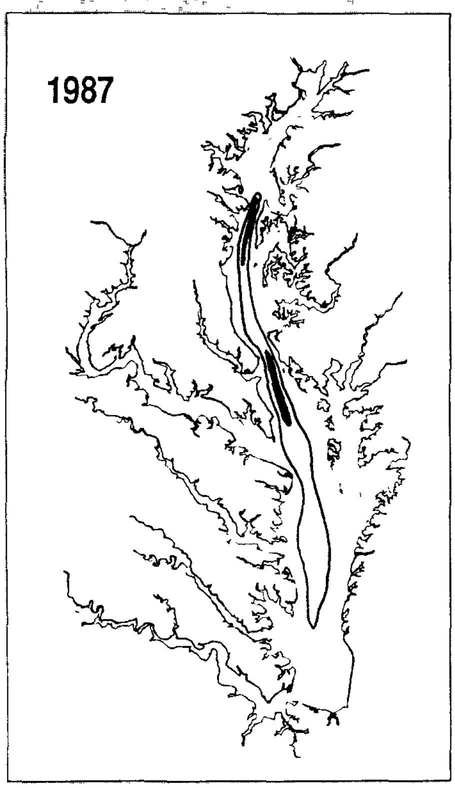
Monitoring of sediment contaminants is critical to track regional trends, understand potential toxic impacts to Bay resources and make dredging decisions. The sediments provide both short and long-term memory of contaminant loadings to the Bay. This information allows scientists and managers to locate hot spots and analyze the effectiveness of our efforts to reduce and eliminate the discharge of toxicants to the Bay. From Susquehanna Flats south to the Bay mouth, polynuclear aromatic hydrocarbons (PAHs) show a significant concentration gradient. The highest concentrations of PAHs range from just south of the Sassafras River (the mainstem's turbidity maximum) to south of the Bay Bridge. A second spike in concentrations shows up at the mouth of the James River, adjacent to the industrialized Elizabeth River. Sediment levels of metals (averaged for 1984 and 1985) peaks off the Patapsco River and gradually decline down Bay until high levels are again seen off the James. The sources of these contaminants are combustion of fossil fuels (PAHs), industrial point sources, urban runoff and upstream sources (metals).

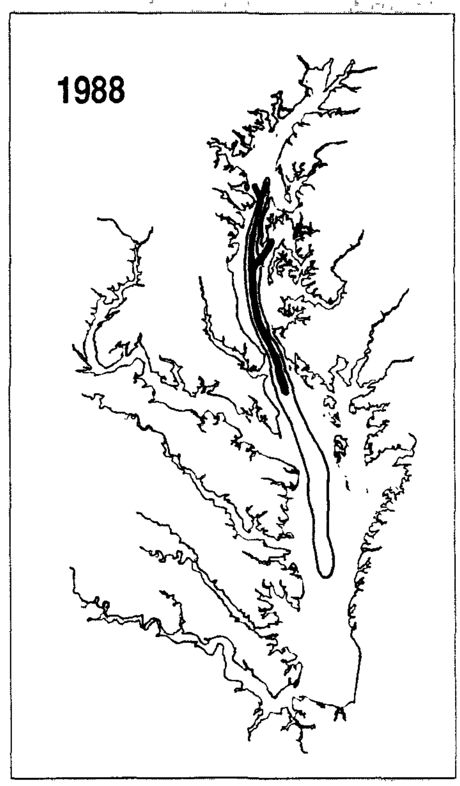
Tracking Dissolved Oxygen in Chesapeake Bay





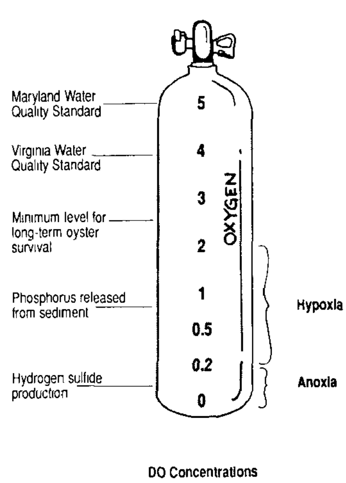






Regions of the Bay's bottom water which become anoxic (lack of oxygen in the water ■) and hypoxic (oxygen levels less than 2 mg/l □) during the summer months are displayed above.

The Importance of Dissolved Oxygen



Low oxygen conditions not only stress the Bay's living resources but also cause production of toxic hydrogen sulfide and enhance the release of phosphorus from the bottom sediments.

Dissolved Oxygen in the Chesapeake Bay

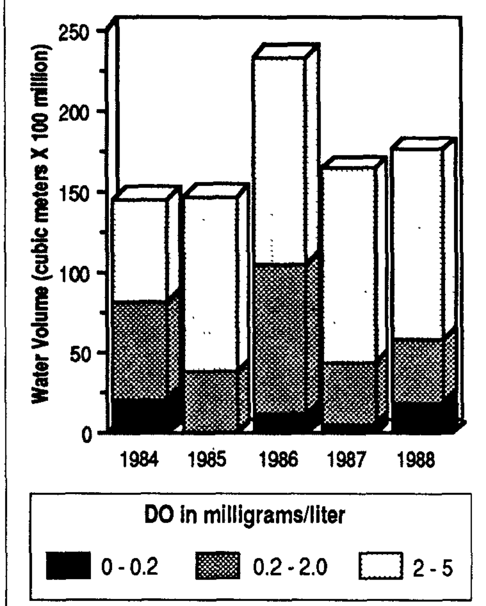
Restoration of dissolved oxygen (DO) to levels required by the Bay's living resources is a central goal of the Chesapeake Bay Program. Through monitoring, scientists and managers have tracked monthly, seasonal and annual changes in the spatial, temporal and volumetric extent of DO throughout the Bay since 1984. Spatial data shown in the preceding maps and corresponding volumetric data on the bar graph are based on the worst DO conditions of each summer. The descriptions below detail the dramatic differences between years which give testimony to the influence of the climate on DO patterns.

In 1984, riverflow into the Bay was well above normal during the winter and spring, contributing large nutrient loads and decreasing surface water salinity. These factors caused increased stratification (layering) which resulted in a long stretch of oxygen-depleted waters near the bottom of the Bay.

Below average river flows translated to reduced nonpoint source nutrient loads and higher surface salinities in 1985. The region of low DO was confined to the area extending from south of the Bay Bridge to the mouth of the Potomac River.

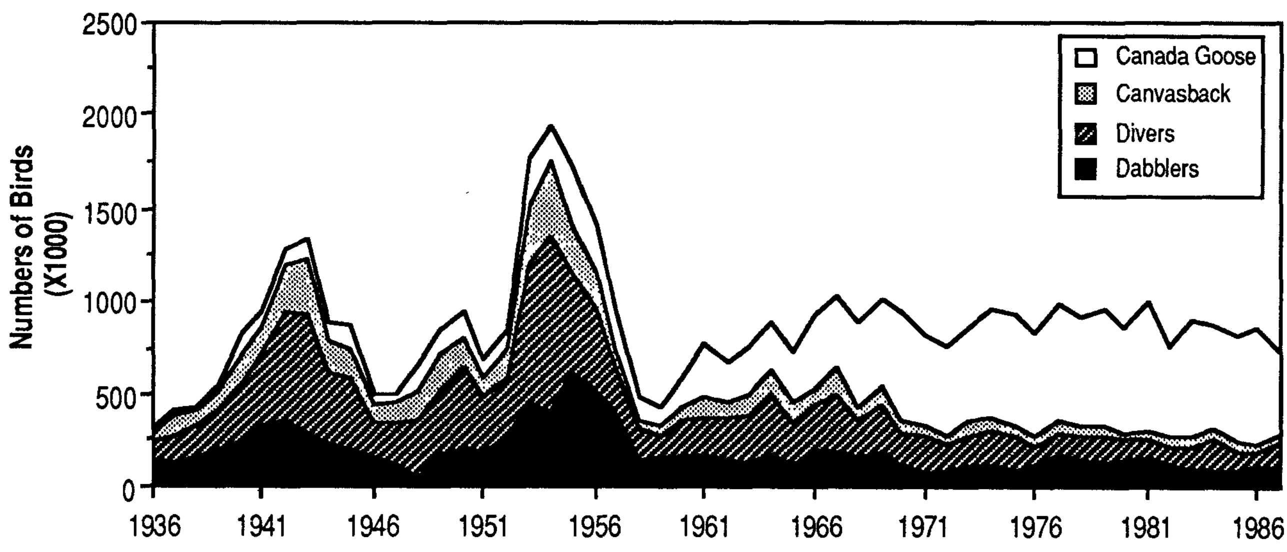
From 1986 through 1988, riverflows remained below normal due to lower than average precipitation in the Bay region. Stratification of the water column was sufficient during the early part of each summer to cause anoxic conditions from north of the Bay Bridge to just south of the Patuxent River. The anoxia, however, did not extend into Virginia waters as occurred in 1984.

Differences in the total volume of low DO waters between years is largely due to early summer meteorological events, the volume of riverflow coming into the Bay each year and the resultant intensity of water column stratification.



Volumes of anoxic (0-0.2) and hypoxic (0.2-2.0) waters in the main Bay as well as waters not meeting state water quality standards (2-5) for DO. The total volume of water in the main Bay is 579 (x 100 million) cubic meters.

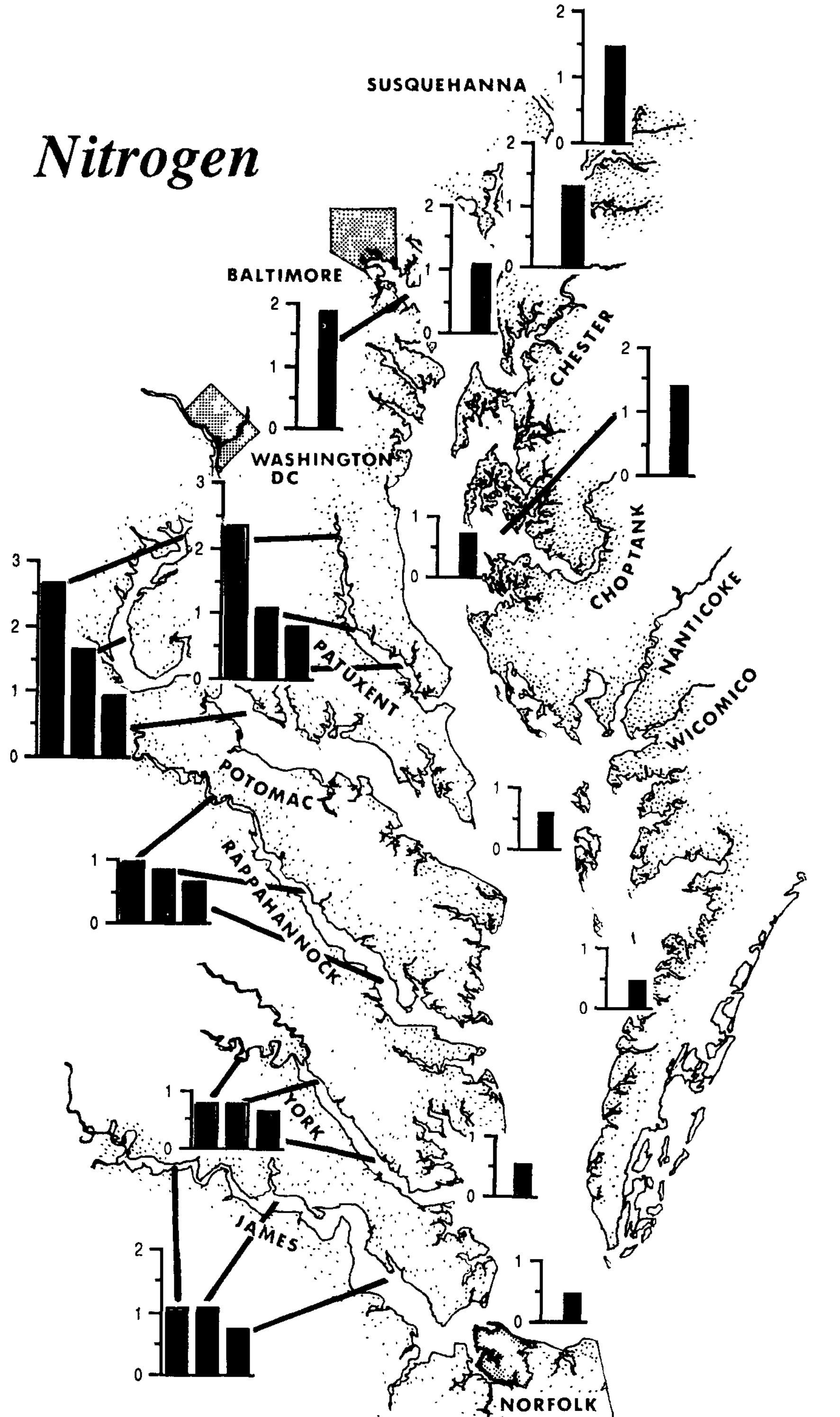
The Waterfowl Picture



Waterfowl, heavily dependent on SAV and several species of invertebrates for food, have been hard hit by nutrient enrichment and toxicant contamination which have degraded the supply of these once abundant foods. The plot of Bay and tributary waterfowl from 1936 to 1987 displays overall reductions in the duck population and an increase in geese stocks. Dabbling ducks such as the mallard, black duck and pintail have fallen from 42% to 12% of the Bay's waterfowl population and diving duck abundance has diminished from 40% to 11%. Over the same period of time, canvasback ducks have remained fairly stable with peaks in the early 1940s and mid-1950s while Canada geese have risen from 11% to 68% due to the ability to shift their feeding to grains left in the field after harvest. Overall duck numbers likely will remain low unless their primary food supplies are restored to more abundant levels.

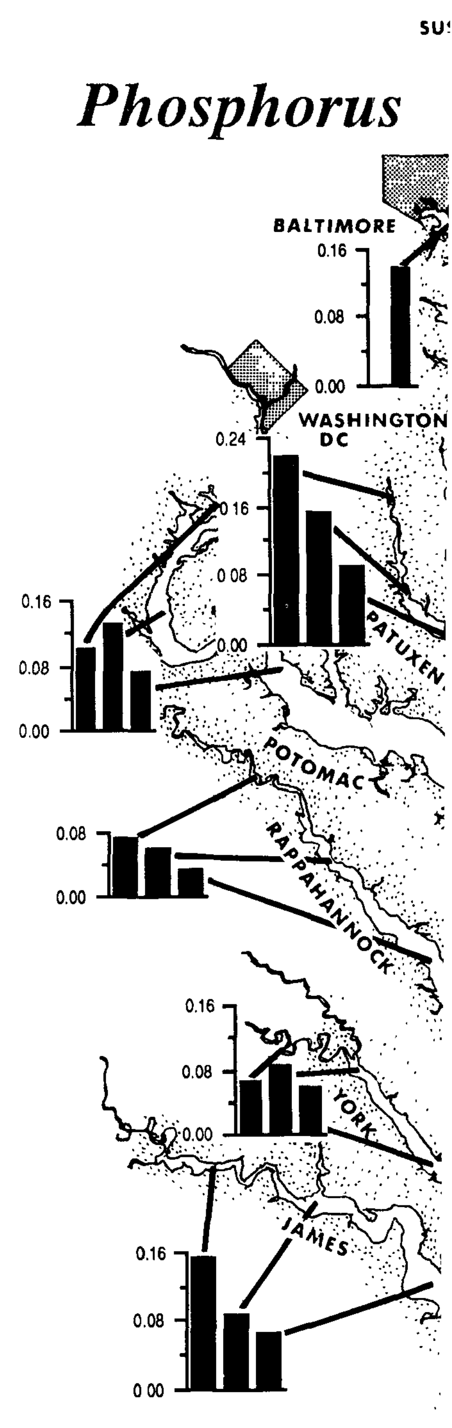
Nutrients and Chloroph

Nitrogen



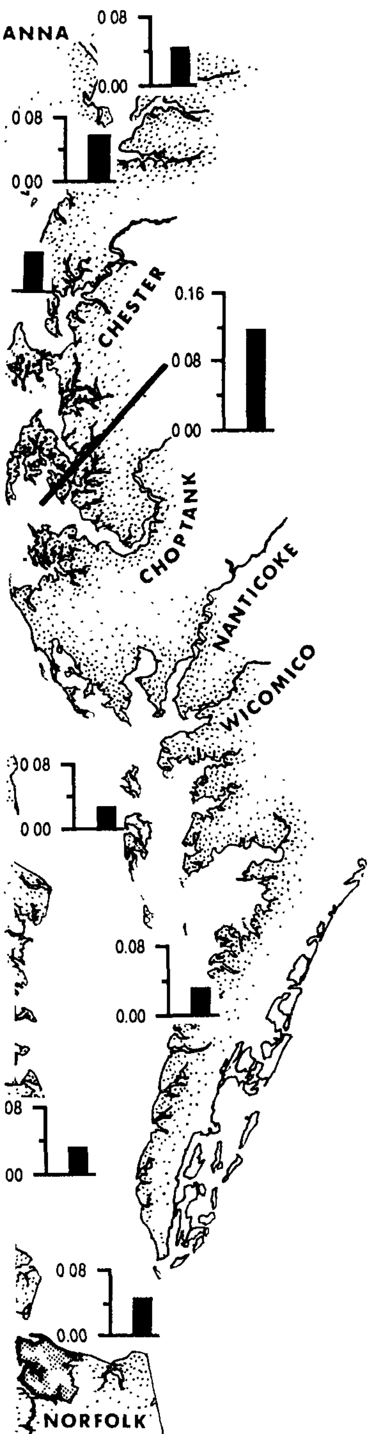
Total nitrogen measured in milligrams per liter for Chesapeake Bay segments based on salinity and circulation zones (tidal fresh, riverine-estuarine transition, lower estuarine). Year- round Maryland and Virginia tributary and mainstem monitoring data from 1984-1988 was averaged to obtain each value. Higher nitrogen concentrations generally occur in the tidal fresh zones, gradually decreasing in the more saline waters found in the tributaries' lower estuarine reaches and the southern portion of the Bay.

Phosphorus

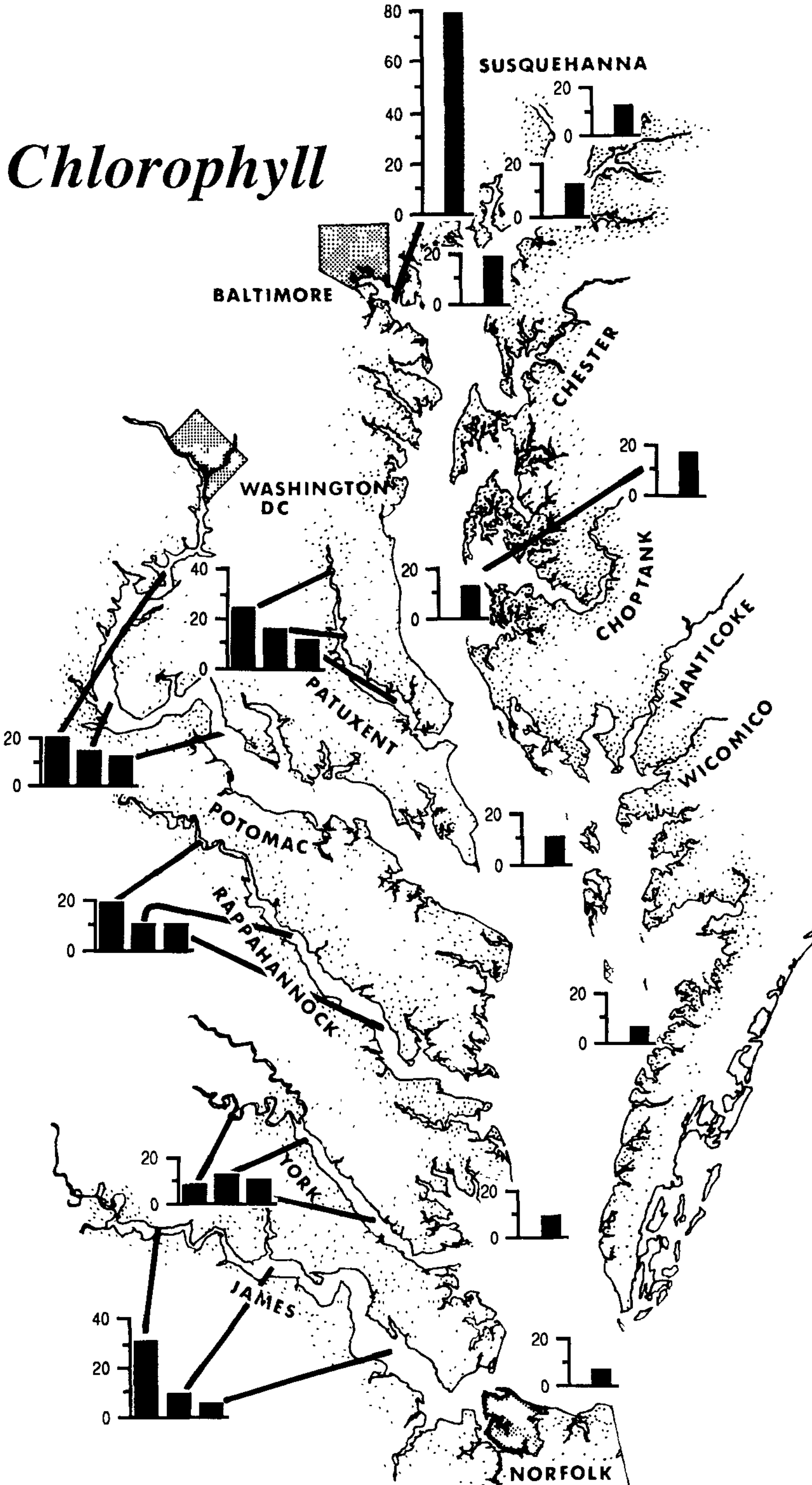


Total phosphorus measured in milligrams per liter for Chesapeake Bay segments based on salinity and circulation zones (tidal fresh, riverine-estuarine transition, lower estuarine). Year-round Maryland and Virginia tributary

l in the Chesapeake Bay



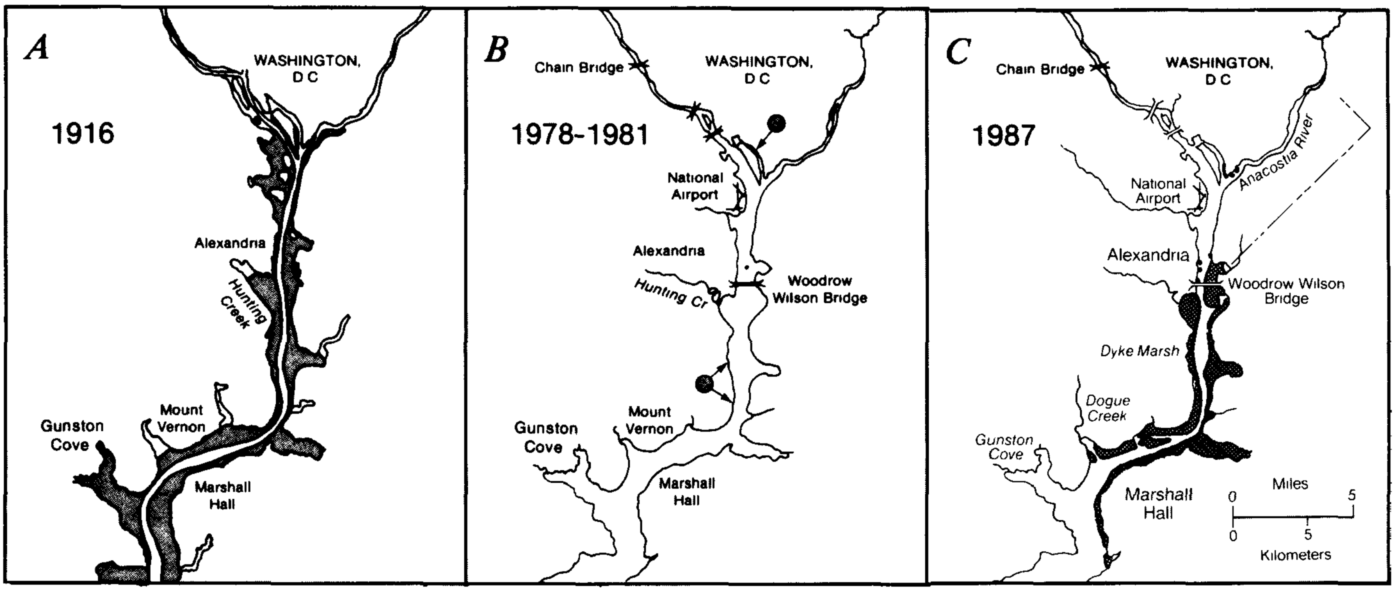
Chlorophyll

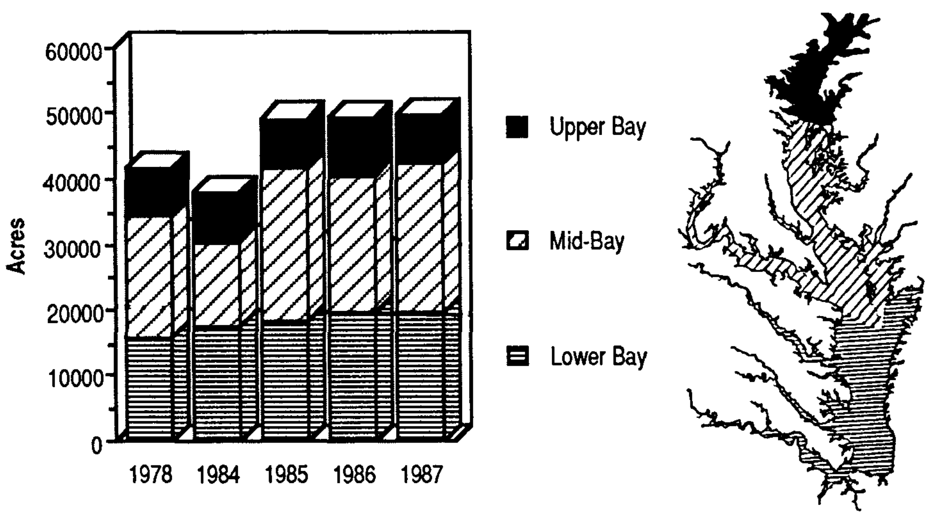


mainstem monitoring data from 4-1988 was averaged to obtain each ue. Higher phosphorus concentra- s generally occur in tributaries ich are in close proximity to point nonpoint sources of this nutrient.

Active chlorophyll measured in micrograms per liter for Chesapeake Bay segments based on salinity and circulation zones (tidal fresh, riverine-estuarine transition, lower estuarine). Summertime Maryland and Virginia tributary and mainstem monitoring data from 1984-1988 was averaged to obtain each value. Higher chlorophyll concentrations generally occur in tidal fresh and transition zones with high nutrient concentrations.

The SAV Story



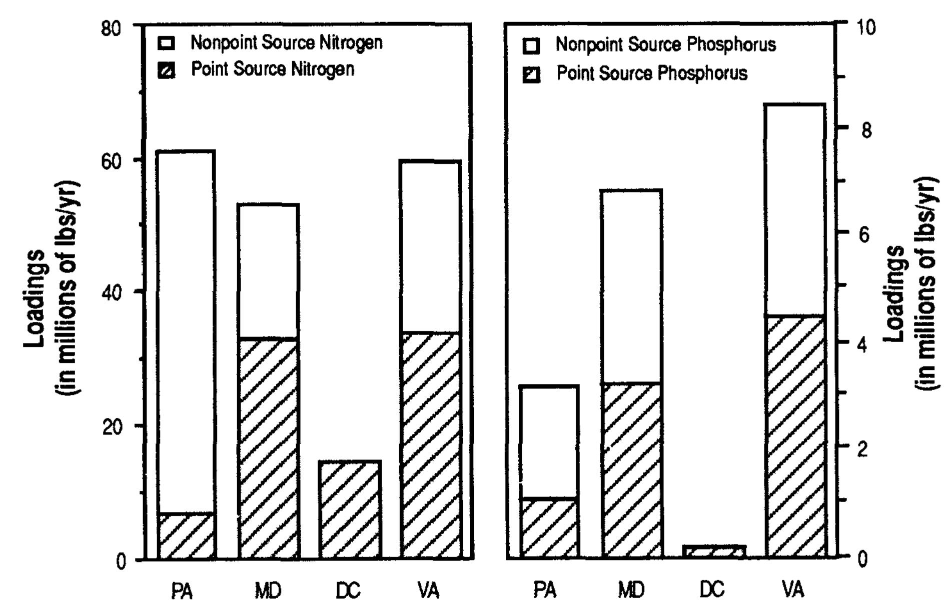


From 1984 to 1987, the acreage of SAV in the Chesapeake Bay has increased 31%, a partial recovery from previous declines. SAV in the lower Bay has shown a steady upward trend—increasing 24% from 1978 through 1987. After a bottoming out in 1984, SAV acreage in the mid-Bay zone increased to 22,900 acres. A large percentage of this increase was due to continued revegetation of the Potomac River and growing widgeongrass populations along the Eastern Shore. In the upper Bay, SAV acreages have remained relatively stable since 1978. Overall, these recent increases in SAV are a positive sign of restoration.

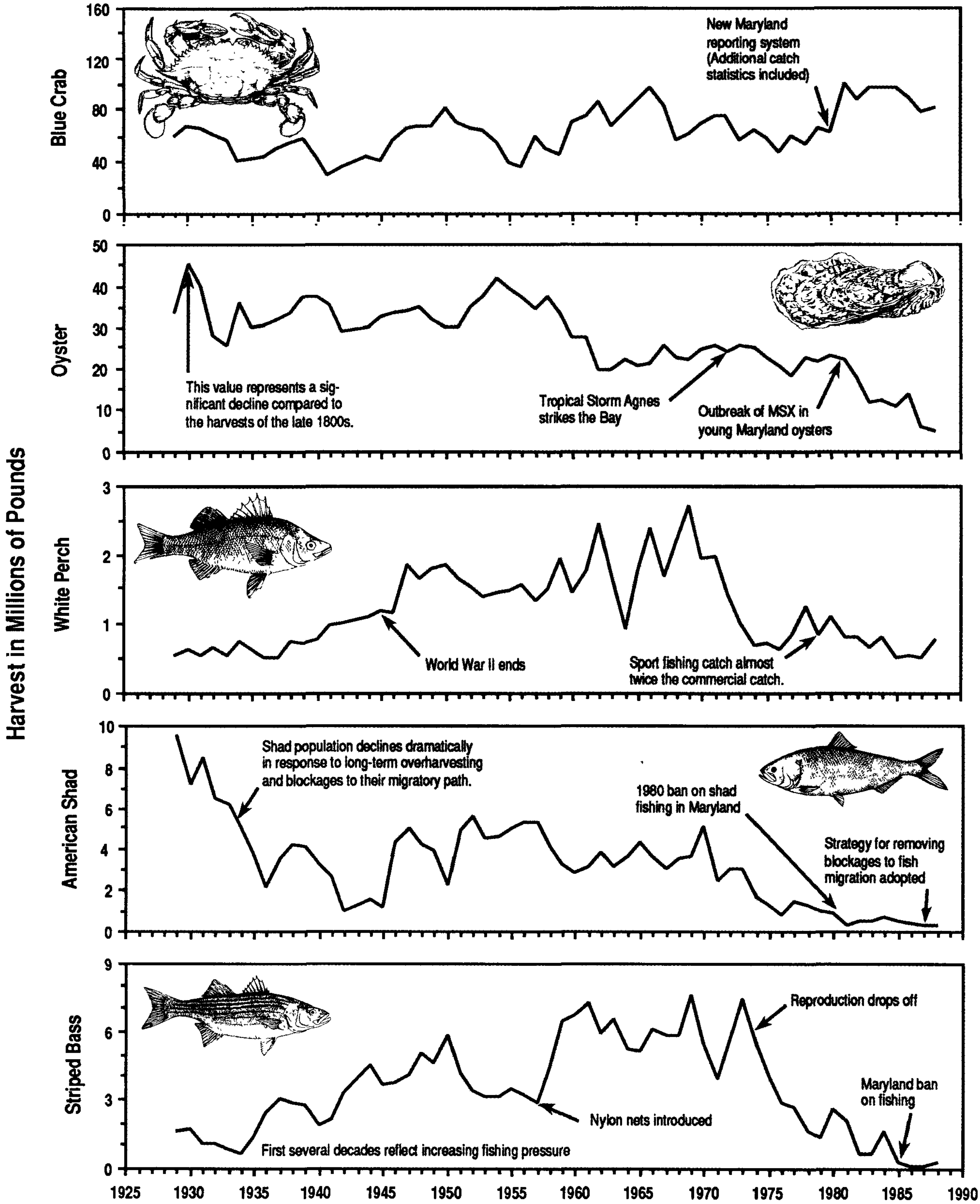
Nutrients Flowing into the Bay

Excessive nutrients pouring into the Bay cause many of the water quality and living resource problems that plague the Chesapeake. Under the 1987 Chesapeake Bay Agreement, plans were made to reduce controllable nutrient loadings to the Bay by 40%. The Agreement also commits the state and EPA to reevaluate the Baywide Nutrient Reduction Strategy in 1991.

Jurisdictions in the Bay region estimated their total point and nonpoint sources of nitrogen and phosphorus loadings to the Bay as well as that portion which is controllable. The total loadings presented here, calculated for point sources as of 1985 and for nonpoint sources in an average rainfall year, show the relative contribution of the sources of these two nutrients from each jurisdiction. *(Source: Baywide Nutrient Reduction Strategy, July 1989).*



Baywide Commercial Fish Harvests from 1929 - 1987



Scientists and mangers use commercial fish harvests as a tool in assessing the status of fish populations over long periods of time. Interpretation is complicated by changes in the level of fishing effort for different species, lack of sportfishing catch data and periodic fluctuations that may result from short-term climatic changes. Commercial harvest data for five important Bay species show that all, with the exception of the blue crab, have declined substantially over the past few decades. Earlier in the century, catches fluctuated due to the amount of fishing effort expended, type of gear used, fish population fluctuations and natural climatic and hydrologic variability. All species showed a catch increase just after World War II when watermen returned to their occupation.

The Bay's Rivers

1989 STATE OF THE BAY

The Bay's rivers—they form the lifeblood of the Chesapeake, supplying fresh water, nutrients and sediment. In this chapter, three rivers illustrate the gamut of problems and solutions facing Bay tributaries. The Susquehanna, draining much of the upper Bay basin, contributes about half the fresh water to the Bay. The Potomac represents the success achieveable with concerted and cooperative efforts. Finally, the Patuxent, site of a burgeoning population, is showing hopeful signs in response to aggressive management actions.

Draining the Land: The Susquehanna

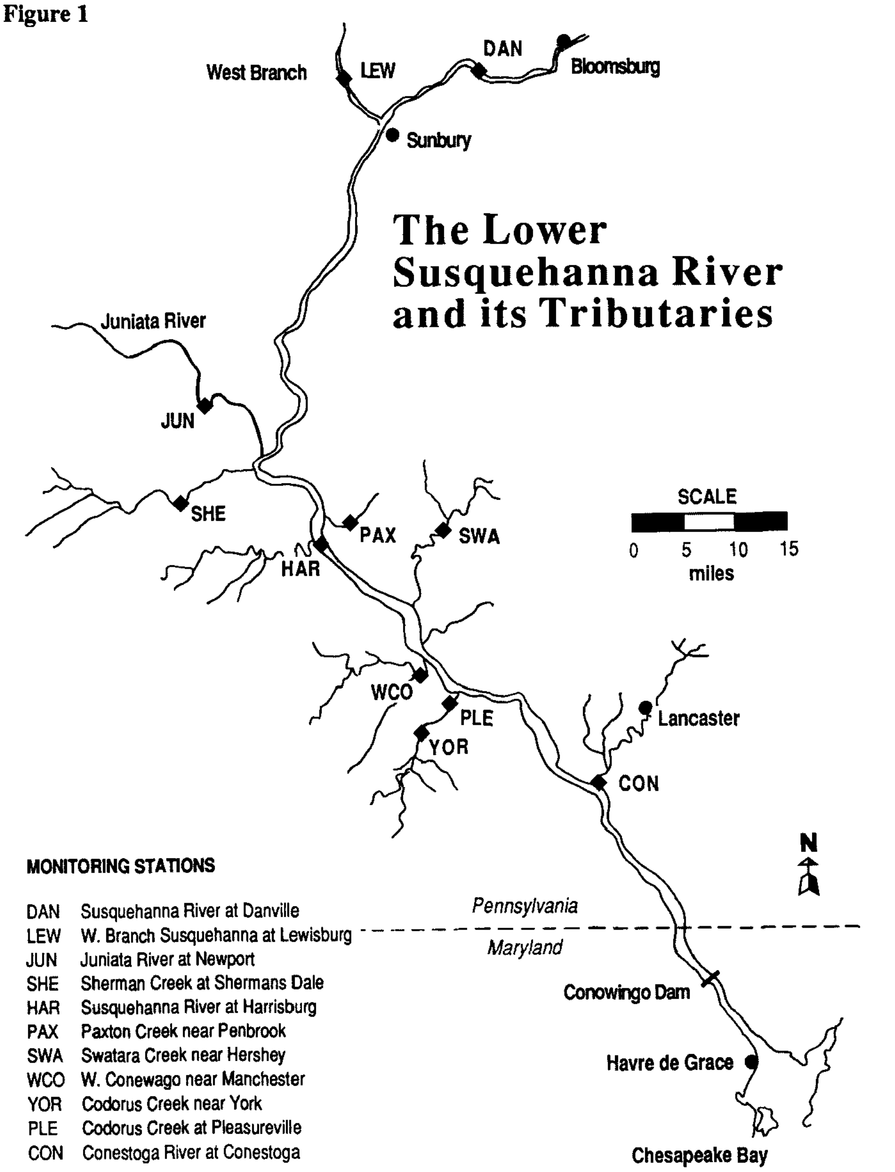
The Susquehanna River, draining an area of 27,500 square miles of New York, Pennsylvania and Maryland, is a major contributor of nutrient loads to the upper Chesapeake Bay. Although some of the nutrient load in the Susquehanna and its tributaries results from point source discharges in the basin, nonpoint source runoff from agricultural land is the major contributor of nutrients entering the Bay from this river. Strategic management of this river, therefore, is exceedingly important for the health of the entire Bay. Carefully planned and coordinated nutrient control measures implemented in the Susquehanna basin will help achieve the nutrient reduction objectives of the Chesapeake Bay Program.

Watershed Monitoring

The Susquehanna River Basin Commission (SRBC), in cooperation with the U.S. Geological Survey (USGS), monitors nutrients and sediment in the Susquehanna River and its major tributaries (Figure 1). The monitoring consists of monthly baseflow and selected storm samples. Using this data, managers estimated how many pounds per acre of total nitrogen and total phosphorus the rivers transported from 1985 through 1988 (Figure 2).

The amount of nutrients transported by the rivers varied somewhat from year to year at each site but showed consistent differences between sites. Watersheds upstream of Harrisburg generally had lower nutrient losses than watersheds to the south. This difference is due to the extensive forests and limited agriculture in the northern Susquehanna River basin. South of Harrisburg, watersheds drain more intensely utilized agricultural and urban/suburban areas, contributing more nutrients and sediments to the rivers. The Conestoga watershed most clearly demonstrates the effects of intensive land use. The Pennsylvania Department of Environmental Resources (PaDER) also conducts routine monitoring through its Water Quality Network program. The network includes 69 stations within the Susquehanna River basin and is coordinated with the SRBC monitoring effort.

Figure 1



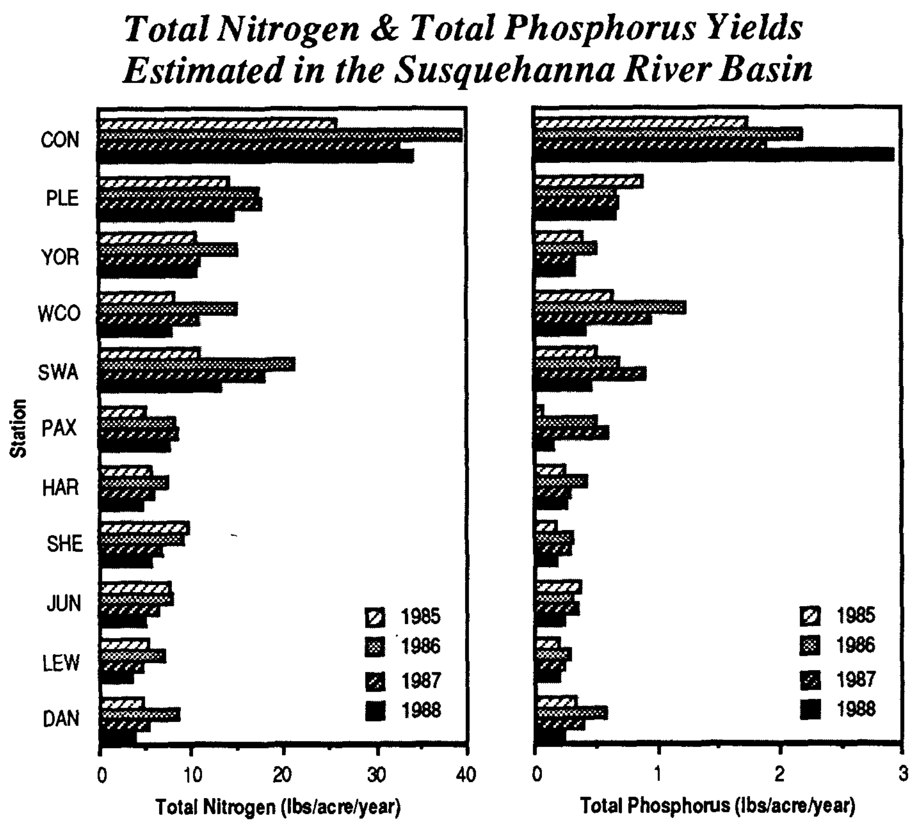
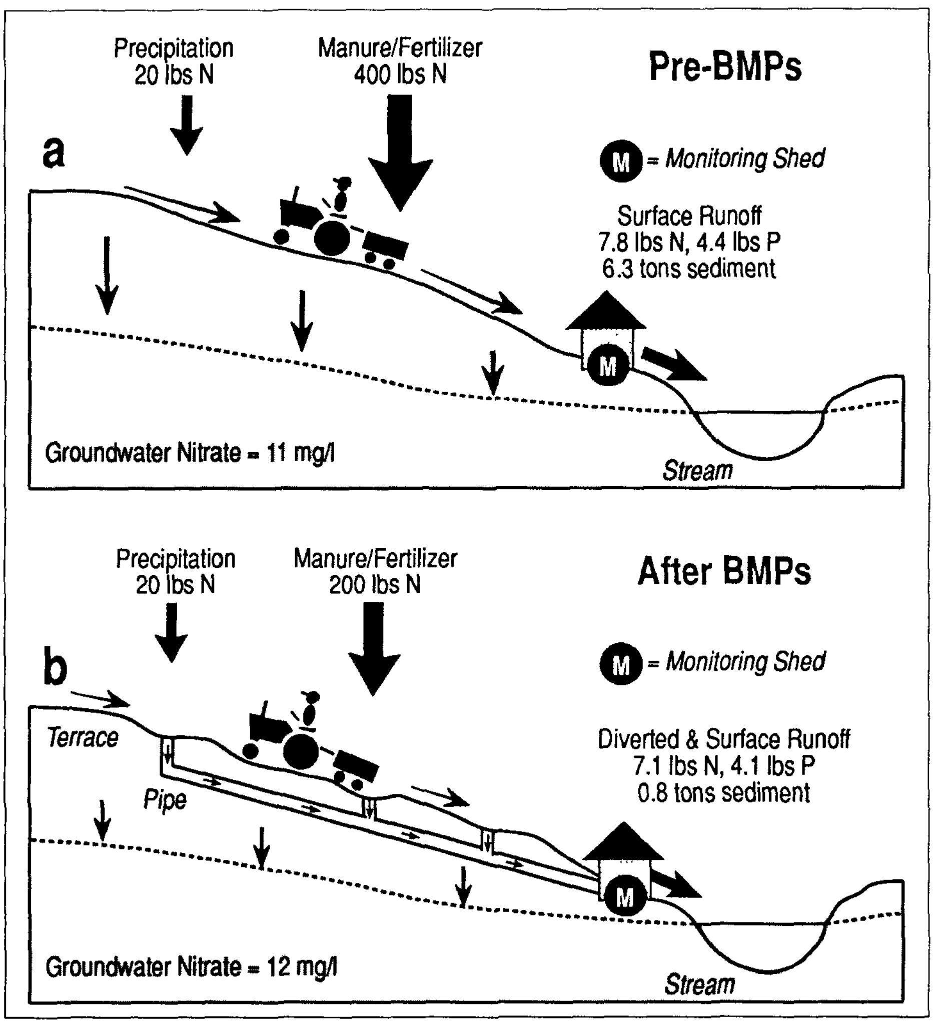


Figure 2. Total nitrogen and phosphorus yields estimated for the Susquehanna basin. There is variation between watersheds, most clearly demonstrated by the agricultural Conestoga watershed. (The map on the preceding page shows the monitoring stations.)



Site-Specific Monitoring

The Conestoga River watershed contributes a major portion of the nutrient load to the Susquehanna River, delivered relatively close to the head of the Bay. The Conestoga, therefore, is of particular concern to Bay nutrient reduction strategies and is a target of nonpoint source pollution controls. An in-depth monitoring program, now in place, will determine the effectiveness of agricultural best management practices (BMPs) in this watershed. The monitoring was initiated as part of the Conestoga Headwaters Rural Clean Water Program (RCWP). The RCWP is a U.S. Department of Agriculture(USDA) program which helps farmers install a variety of BMPs within the project area.

The water quality monitoring portion of the RCWP was a cooperative effort between the PaDER and the USGS with substantial assistance from the USDA and Penn State University. Two large farm field sites are now monitored for the Chesapeake Bay Program by USGS for groundwater and surface runoff. Surface water is studied at a small watershed site. The strategy at each site calls for pre-BMP measurements followed by additional monitoring after the BMPs are in place.

At one site, located on a traditional Lancaster County dairy farm, the farmer implemented various BMPs to improve water quality. The BMPs included terracing slopes and changing crops to control runoff. A manure storage facility alleviated the problem of having to spread the manure during inclement weather. In addition, based on the nutrient needs of the crops, the managers developed a nutrient management plan which recommended lower application rates of fertilizer and manure.

Figure 3. Preliminary results of two best management practices (BMPs)—terracing and nutrient management—applied to a dairy farm in Lancaster County. Runoff was monitored before (1983 to 1984) and after (1987 to 1988) implementation of the BMPs. Nitrogen application to the land was reduced, resulting in less nitrogen washing from the site as surface runoff. Sediment runoff decreased much more dramatically; phosphorus runoff also decreased. Groundwater nitrogen levels have increased, possibly from water movement shifting from surface runoff to groundwater and residual nitrogen stored in the soil.. Additional responses may develop after these BMPs have been in place longer. (All values are per acre per year; N = Nitrogen; P = Phosphorus)

Monitoring at the field sites has yielded preliminary results concerning the complex relationship between land use and water quality. There may be trade-offs between BMPs designed to improve surface water and those protecting groundwater. Terraces, for example, reduce sediment and nutrient loadings to surface runoff but may also allow more nitrate into the groundwater in permeable soils which have received overapplications of nutrients. To prevent groundwater degradation in such areas, terraces should be used in conjunction with nutrient management. As an alternative, farmers could use other methods of controlling sediment losses in combination with nutrient management.

Using Data for Management

Pennsylvania ultimately uses the monitoring data to support management decisions. The data assist in ranking areas for remediation ensuring that the managers expend funds on those projects providing the maximum reduction in nonpoint loadings. The SRBC/USGS watershed monitoring has quantified substantial differences related to land use patterns and resultant nonpoint source pollution impacts. Clearly, some watersheds such as the Conestoga require more attention than others.

The monitoring data also improve calibration of the computer model of the Chesapeake Bay watershed. This model provides managers with the ability to project and evaluate water quality improvements from various nonpoint source pollution control options. Both types of monitoring described above supply the much needed information to refine and calibrate this model.

Finally, monitoring data collected over the years will show whether nonpoint source pollution control in the watershed has helped improve water quality in the streams and ultimately in the Bay itself. This information needs to be collected at both the site-specific and watershed levels and at the mouth of the Susquehanna River where the nutrients and sediments are finally delivered to the Bay. The Maryland Department of the Environment and the USGS cooperate to measure these loads entering the Bay and are coordinating efforts with Pennsylvania to understand their derivation in the watershed. Lessons from the Susquehanna reinforce the concept that the Bay will be only as healthy as the water coming into it.

Road to Recovery: The Upper Potomac

The upper Potomac River is one of our nation's major success stories in water quality restoration. Considered grossly polluted and a national disgrace in the 1960s, it is now a healthier, more productive estuary. This dramatic improvement is the result of aggressive pollution abatement programs undertaken by state, local and federal governments during the 1970s and 1980s.

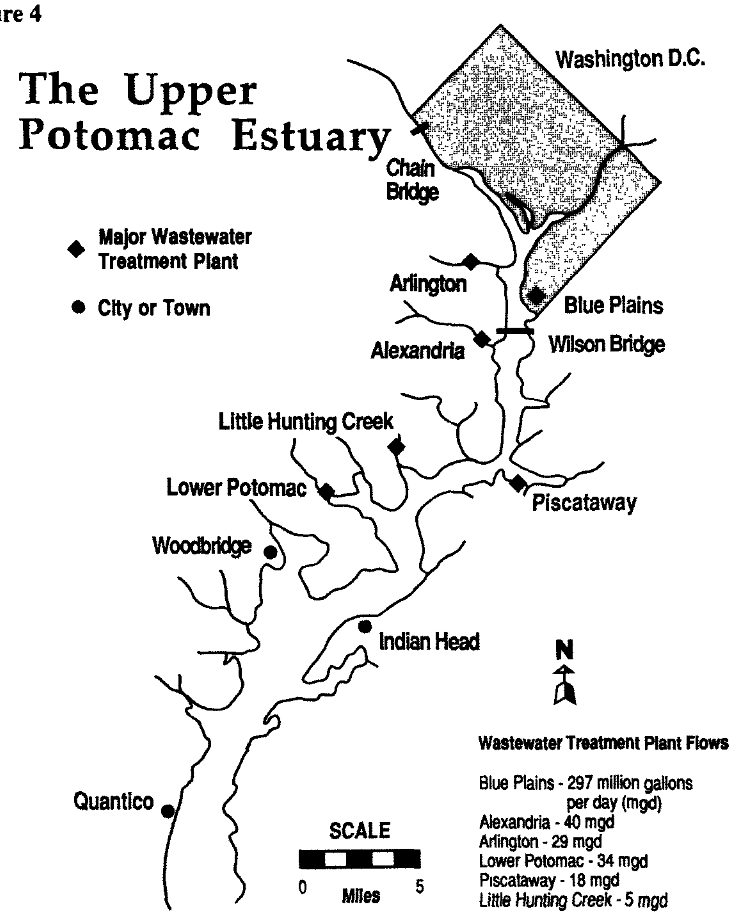
The Decline of the Nation's River

Concern over the Potomac River's water quality and living resources grew over many decades. As its health worsened, nuisance algal blooms, low dissolved oxygen (DO), bacterial contamination, disappearance of submerged aquatic vegetation (SAV) and declines in the fisheries came to plague the once bountiful river. In 1925, the Public Health Service declared the Potomac in Washington D.C. unsafe for bathing due to sewage pollution. Nutrient pollution, primarily nitrogen and phosphorus from wastewater treatment plants, led to the Potomac's algal blooms which were clearly visible as large blue-green surface mats. These blooms, along with organic matter from sewage, caused depletion of the water's DO upon decomposition. Furthermore, the blooms and excess nutrients have been implicated in the decline of SAV which forms important fish habitat. In 1916, the upper Potomac harbored abundant SAV but a survey revealed virtually no plants in the river between Chain Bridge and Quantico, Virginia by 1978-1981.

The Root of the Problem

Nutrient pollution is a primary cause of problems throughout the upper Potomac estuary. It comes from both point sources, primarily the sewage treatment facilities serving the Washington, D.C. metropolitan area, and from nonpoint sources, such as rainwater running off agricultural and urban land. In addition to nutrients, point sources contribute organic matter which can rob the river of DO upon decay (measured as biochemical oxygen demand—BOD). If not properly treated, these sources may also introduce bacteria to the water.

Figure 4



Point source inputs are relatively constant throughout the year due to the population's consistent generation of waste. Because sewage wastes are collected at centralized facilities, their treatment is feasible and practical. Nonpoint source inputs, however, are greatly variable—high during storms or wet seasons and minimal during dry spells. Nonpoint pollution is much more difficult to control because the sources enter the river through many routes and are episodic.

Responding to the Problems

Until recently, sewage treatment plant discharges were the primary type of pollution entering the upper Potomac. The improved treatment of these wastes, therefore, has been the primary focus of the Potomac cleanup.

Up to 1938, when the Washington D.C. Blue Plains wastewater treatment plant (WWTP) started operation, raw sewage flowed directly into the Potomac River. At that time, Blue Plains was able to process 130 million gallons of wastewater per day (mgd) to a primary treatment level—simply a screening and settling of wastes. This level of treatment typically reduces nutrients by about 20% and BOD by 50%.

Blue Plains applied secondary waste treatment in 1959 after a recommendation from the first Potomac Enforcement Conference which met in 1957. Secondary treatment aerates the wastewater, using bacteria to break down the organic matter. This process reduces BOD considerably more than primary treatment. The conference met again in 1969 and recommended a 96% removal of phosphorus, a 96% reduction of BOD and an 85% removal of total nitrogen from Blue Plains effluent, setting a timetable for achievement of these goals by late 1977.

The Federal Clean Water Act, enacted in 1972, set clean water goals nationwide and increased the federal government's role in cleaning up the Potomac. In 1974, the EPA issued National Pollutant Discharge Elimination System (NPDES) permits which implemented the second Potomac Enforcement Conference guidelines.

Along with $250 million from state and local governments, the EPA contributed $750 million in the 1970s to improve WWTPs along the Potomac. Improvements included adding secondary treatment, advanced treatment (the addition of chemicals to further reduce nutrient levels) and chlorination to eliminate bacterial contamination. Both phosphorus and nitrogen control were originally called for but only phosphorus removal was implemented. Managers felt that nitrogen removal was not economically feasible at the time and hoped that phosphorus removal alone might limit algae growth.

Blue Plains treatment plant was issued a new NPDES permit in 1979 which did not limit total nitrogen, thereby omitting denitrification. The permit did call for a staged reduction in effluent phosphorus concentrations from 1.6 mg/l to 0.22 mg/l by 1986. The plant attained a limit of 0.23 mg/l phosphorus in 1982.

In 1982, the Potomac Eutrophication Model (PEM), a mathematical model of water quality, was developed to help understand the nutrient enrichment dynamics (eutrophication) of the upper Potomac. In response to model results and the federal and state regulating agencies' perception that the river was not yet restored (there was a severe algal bloom in 1983), regulators decided that WWTPs could not expand without keeping phosphorus levels stable. To comply, the expansion of Blue Plains from 309 mgd to 370 mgd required a limit on total phosphorus of 0.18 mg/l down from the 0.22 mg/l allowed at the lower discharge rate of 309 mgd. Implemented in 1987, this new phosphorus limit superceded the NPDES permit of 1979.

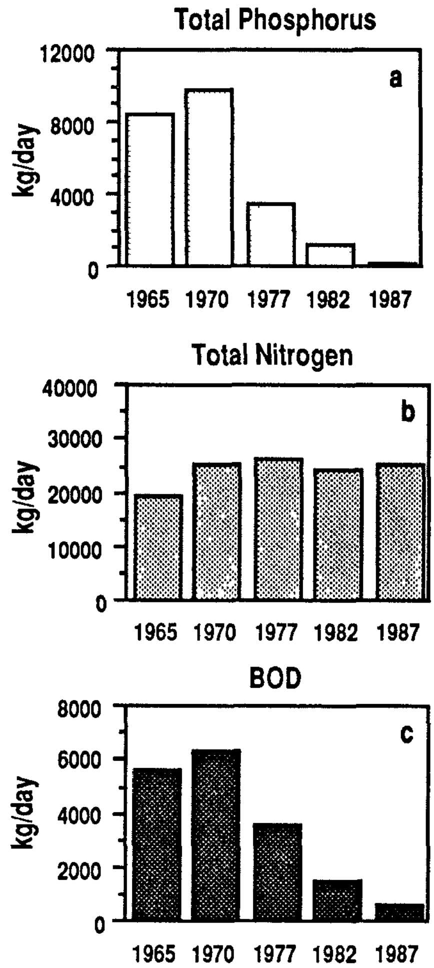


Figure 5a-5c. Loadings from the major WWTPs (see Figure 1) discharging into the upper Potomac. Total phosphorus and biochemical oxygen demand both show substantial declines as a result of management actions in the 1970s. Total nitrogen remained relatively constant despite the increase in wastewater handled by the plants.

In another effort to limit phosphorus entering the Potomac and all Maryland tributaries, the Maryland legislature passed a law in 1985 banning phosphates in detergent. The Maryland ban went into effect in 1986. Washington DC initiated a ban on phosphate detergents in 1986 and Virginia implemented a statewide ban in 1987.

These management actions are responsible for significant reductions of point source pollution entering the upper Potomac. The reduction in the total phosphorus load from major wastewater treatment plants has been dramatic, dropping from a high of about 10,000 kg/day in 1970 to less than 300 kg/day in 1987 (Figure 5a).

Total nitrogen loads from the WWTPs have remained relatively constant since 1970 (Figure 5b). Although the plants are not specifically designed for nitrogen removal, secondary and advanced treatment processes remove some nitrogen along with the phosphorus. Nitrogen loads have not increased, therefore, despite the increase in wastewater handled by the plants.

BOD increased steadily in the upper Potomac from 1913 until the addition of secondary treatment at Blue Plains in the late 1950s when it dropped almost 50%. BOD gradually rose again until cleanup programs in the 1970s imposed stringent restrictions on WWTP effluents. These programs were instrumental in reducing the BOD by over 85% from 1970 through 1987 (Figure 5c).

The River Comes Back

As pollution entering the Potomac has come under control, water quality trends measured at representative sampling stations in the upper estuary between Piscataway Creek and Indian Head showed dramatic improvement from 1965 through 1988 (Figure 6a-6e).

Total phosphorus in the river has decreased in concert with phosphorus removal from the WWTPs in the 1970s (Figure 6a). The decline in this nutrient coincides more closely with its removal in the 1970s than in the 1980s, suggesting that the system was more strongly influenced by point source loadings in the 1960s and 1970s. Other factors, such as nonpoint sources, are becoming more significant in the 1980s. The water quality monitoring now includes nonpoint source inputs from the entire river above Washington.

Total nitrogen in the upper Potomac has not varied appreciably from 1965 through 1988 (Figure 6b). As stated, loadings changed minimally over this time period.

Chlorophyll, a measure of algal abundance, has been decreasing in the upper Potomac since the mid-1960s (Figure 6c). Although the overall trend is dropping, some blooms have occurred since the 1960s. Favorable climatic and hydrologic conditions likely fostered the more recent blooms of 1981 and 1983. Despite similar conditions observed in 1988, no major algal bloom developed, signifying that the massive algal blooms of the past may finally be under control.

Dissolved oxygen (DO) is vital to most life and is a key measure of an estuary's health. Nutrient control programs of the 1970s have improved DO conditions by reducing blooms which eventually decay and consume large quantities of oxygen. The reduction of organic wastes in effluent has also reduced the amount of oxygen needed for its decomposition once it enters the river. Since the mid-1970s DO has increased in the upper Potomac, indicating the improving health of the system (Figure 6d).

Water clarity determines the amount of light available for the growth

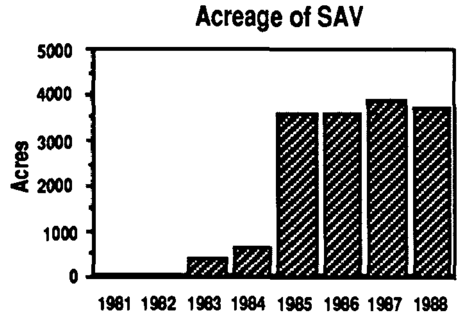


Figure 7. SAV showed a formidable recovery from the all-time lows of the early 1980s. Scientists attribute its reemergence to improved water quality.

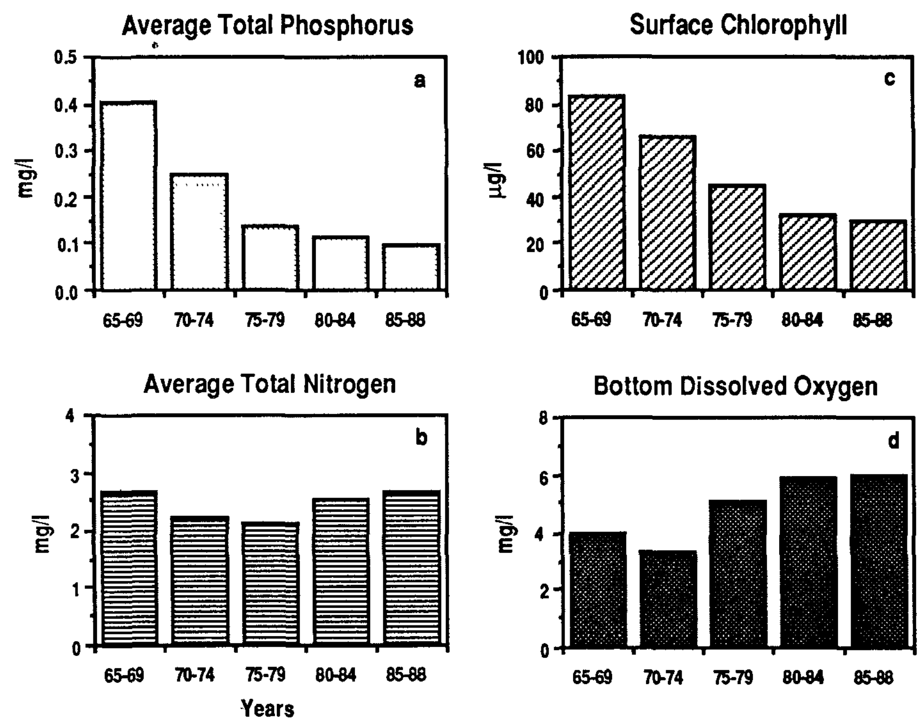
and survival of SAV. An abundance of suspended matter can destroy SAV and bottom organisms by settling and covering them, denying them light and oxygen. Clarity has shown a steady increase (Figure 6e), enabling light to penetrate to greater depths and making conditions more favorable for the resurgence of SAV.

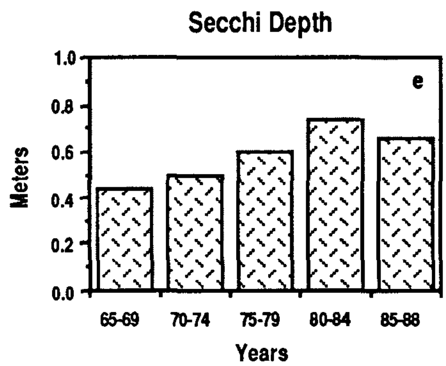
Degradation of the Potomac's water quality was directly responsible for the sharp decline of SAV. After being almost nonexistent for nearly 20 years, SAV returned to the upper Potomac in 1982. The U.S. Geological Survey and baywide aircraft surveys estimated that SAV areal coverage has increased from 400 acres in 1983 to over 3600 acres in 1985 (Figure 7). The reemergence of the SAV can be attributed to several water quality improvements including nutrient reduction, lower chlorophyll and better water clarity.

Some fish species also appear to be responding to improving habitat conditions. Largemouth bass fishing in the upper Potomac was almost nonexistent 10 years ago because degraded water quality and lack of SAV in the upper Potomac provided poor habitat. Today the recreational bass fishery is booming. The reemergence of SAV was crucial to the fishery's recovery.

The abundance of waterfowl and diversity of waterfowl species have also increased in the upper Potomac. Both the U.S. Geological Survey and the National Park Service reported a significant increase in waterfowl numbers in the SAV beds. Hydrilla, an introduced species accounting for much of the SAV resurgence, is a preferred food for numerous species of waterfowl, supplementing the less abundant native SAV species. Other waterfowl that do not graze on SAV are probably feeding on the supply of fish and invertebrates inhabiting the SAV beds.

Water Quality in the Upper Potomac Estuary





Figures 6a-6e. Since 1965, the upper Potomac has shown substantial water quality improvements in response to reductions of loadings from wastewater treatment plants (Blue Plains, in particular). The improvements are characterized by increased water clarity (greater secchi depth), lower levels of surface water chlorophyll, lower concentrations of total phosphorus, and greater levels of dissolved oxygen in the bottom waters. Total nitrogen has remained relatively constant.

Recreational activities along the upper Potomac increased during the mid-1970s as the river once again became an attraction for people— instead of a "national disgrace." In 1978, the District of Columbia organized the first annual Potomac River Raft Race and in 1981 held the first annual Potomac River Festival. The surge in recreational boating and sport fishing has continued throughout the 1980s.

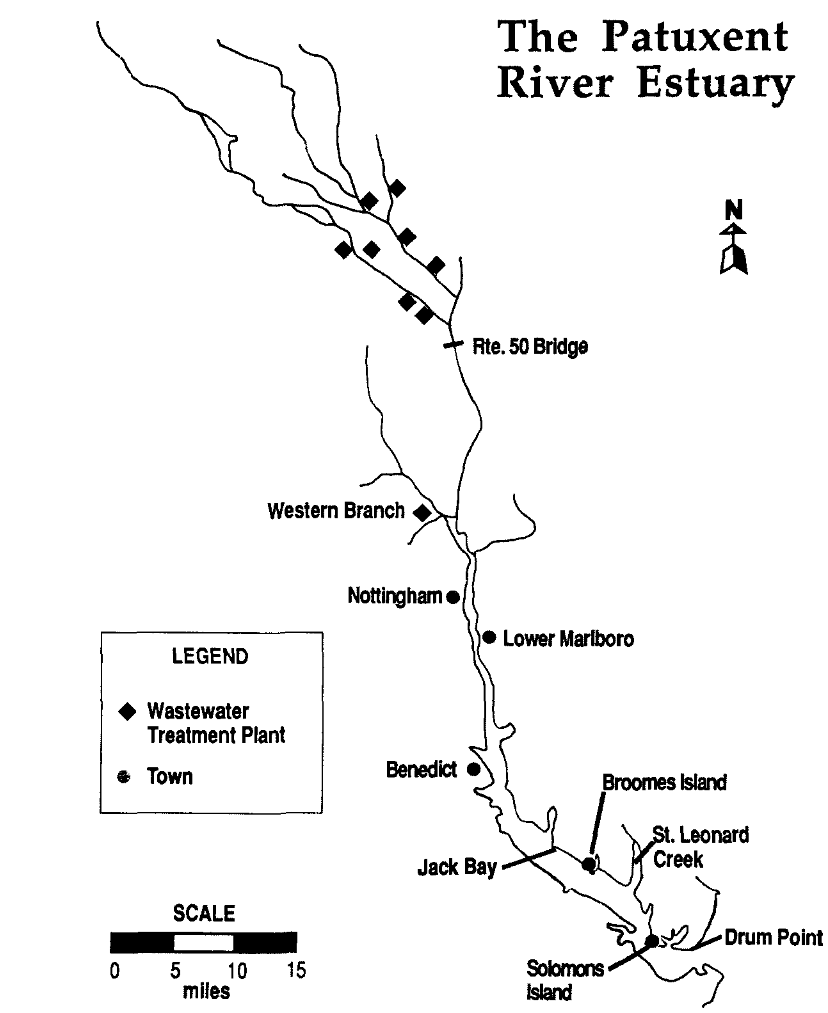
Dramatic reductions in point source pollution have produced steady improvements throughout the upper estuary. Although we have come a long way, additional challenges remain. More information on fishery improvements is required to ensure that the system has returned to a healthy state. Conditions in the lower estuary should be closely monitored for response to improving health and productivity upriver. Most importantly, nonpoint source pollution will have to be controlled as it becomes the dominant source of pollution entering the estuary.

Progress in the Patuxent

The Patuxent River, a major Chesapeake Bay tributary, has experienced disturbing declines in water quality in recent years. Rapid population growth within the watershed has resulted in major land use changes and increasing demands on its municipal wastewater treatment facilities. As the population surged from 134,000 in the 1960s to 348,000 by 1980, WWTP flows increased significantly, from 3 mgd in 1963 to 36 mgd in 1980. Land development climbed, particularly in the upper watershed, with a 4% loss of agricultural land.

Increasing population and urbanization of the watershed have increased nutrient loads to the Patuxent from both point and nonpoint sources (Figure 9). Water quality has responded with higher peak algal concentrations and critically low levels of summertime DO in the lower estuarine reaches (Figure 10).

Figure 8



Maryland's Action Plan in the Patuxent River Basin (January 1982)

- Reduce total phosphorus (TP) and total nitrogen (TN) loadings from point sources to 191 kg/day and 1832 kg/day, respectively.
- Reduce nitrogen from nonpoint sources by 907 kg/day.
- Initiate a coordinated monitoring, modeling and research program to reduce uncertainty and confirm system response.

Management Actions

Federal, state, local and academic officials convened in December 1981 to formulate a strategy aimed at reversing the trend of water quality degradation. The participants used the best available scientific information, including the results of a short-term, intensive monitoring program and a steady-state water quality model, to identify the causes of water quality decline.

As a result of the meeting, Maryland developed and adopted the Patuxent Nutrient Control Strategy (January 1982) which outlined specific nitrogen and phosphorus reduction goals for point and nonpoint source pollution. The agreement also called for a coordinated monitoring, modeling, and research program to reduce scientific uncertainty and track the response of the Patuxent to management actions.

Making Headway

Maryland has made considerable progress in implementing the goals of the Patuxent Strategy. The state initiated a program of phosphorus removal from point source discharges in 1982, followed by a statewide ban on phosphate detergents in December 1985. These actions have dramatically lowered WWTP inputs of phosphorus (Figure 9). Nitrogen removal facilities are under construction at the Western Branch sewage treatment plant and should be completed in 1990. Upgrading the Western Branch facility is the state's major step towards meeting the point source nitrogen removal goals.

As recommended by the strategy, Maryland established a comprehensive Patuxent Estuary Monitoring, Modeling

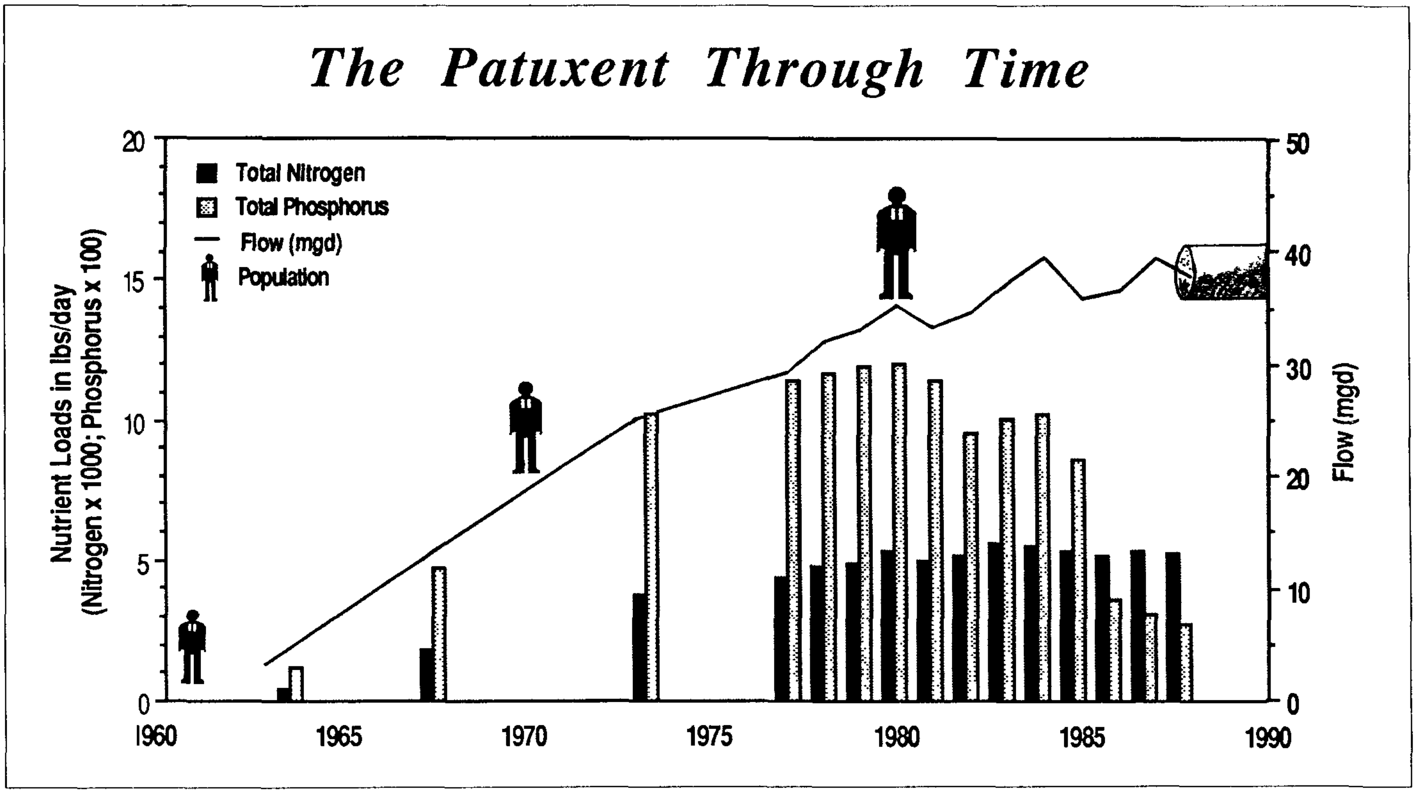


Figure 9. Historical declines of water quality in the Patuxent estuary were accompanied by trends of increasing population, waste-water treatment plant flows and point source nutrient loads. Recent management actions have greatly reduced phosphorus loadings.

and Research Program in 1983. Intended to expand understanding of water quality problems, the program provides periodic assessment of improvements, and if necessary, guides modification of the Patuxent Strategy's nutrient reduction goals. The results of the monitoring program will provide evidence of advancements in water quality due to imposed nutrient controls.

System Response to Nutrient Control

To date, phosphorus has been more stringently controlled than nitrogen and shows a larger decrease in water column concentrations. Total phosphorus at the head of tide (Figure 11) and in the upper estuary has dropped about 30 to 40% since 1983. Nitrogen, however, shows little more than natural variability over the same period.

Although the results of phosphorus reductions are clearly visible in the upper estuary, the lower areas do not yet show similar recovery. Since the upper basin contains most of the major WWTPs, with only one major WWTP (Western Branch) discharging directly to tidal waters, nutrient controls will have the greatest initial impact on the upper basin water quality. The effect of

Progress to Date:

The current point source loading of 140 kg/day is below the established goal of 191 kg/day. This phosphorus load is achieved by requiring all WWTPs with flows greater than 0.5 mgd to meet a 1 mg/l phosphorus effluent concentration.

Future Plans:

Completion of nitrogen removal facilities at the Western Branch sewage treatment plant in 1990 will bring point source nitrogen loads to 1773 kg/day, less than the goal of 1832 kg/day.

Anticipated Needs:

Sewage flows are projected to reach 64.5 mgd by the year 2000. In order to maintain the current nutrient removal goals, some plants will need to remove phosphorus to a level of 0.3 mg/l, and all plants will need to incorporate nitrogen removal practices.

Minimum Levels of Dissolved Oxygen Along the Axis of the Patuxent Estuary

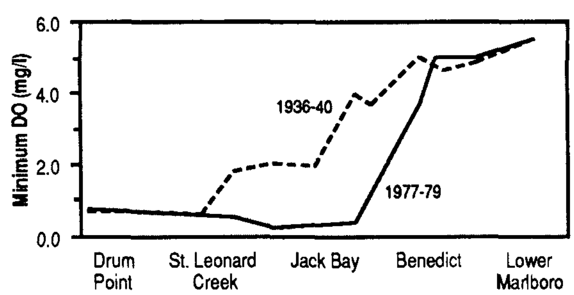


Figure 10. Declines in water quality are exemplified by the more extensive region subject to summer depressions of dissolved oxygen during 1977 to 1979 compared to 1936 to 1940.

Phosphorus in the Patuxent

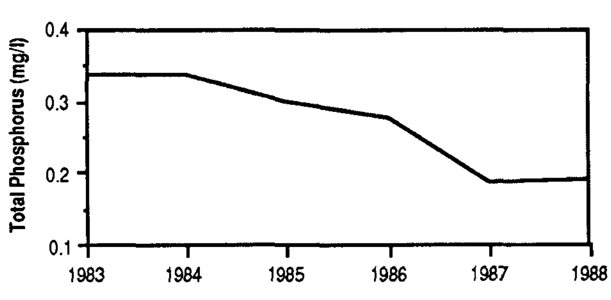


Figure 11. Phosphorus concentrations at the Route 50 bridge have shown significant decline since the 1981 Patuxent Agreement, in response to decreasing loads to the estuary.

upriver nutrient removal is less pronounced downstream due to the distance from the point sources, the influence of the Bay and sediment nutrient releases.

Projected Water Quality Response

Maryland used monitoring data from 1983 to 1986 in the development of a water quality model to assess future benefits of the Patuxent Strategy. The model predicts significant water quality improvements should occur throughout the estuary if all controls recommended by the strategy are implemented. In addition to reduced nutrient levels in the water, the model predicts decreased chlorophyll and increased DO.

Around Nottingham, the region of highest chlorophyll levels, the model projected a decrease in peak concentrations from approximately 70 µg/l in 1983 to 50 µg/l with all nutrient controls in place. During the summer, the biomass of algae throughout the estuary should decrease by about 25% with nutrient controls. Of the 25% reduction, the model attributed 18% to phosphorus control strategies with an additional 7% occurring with both phosphorus and nitrogen controls.

The projected reduction in algal biomass would also reduce the amount of oxygen-consuming organic matter settling and decaying on the bottom. With the nutrient controls of the strategy and the resultant reduction in biomass, the model projected that DO would increase by approximately 0.6 mg/l in the bottom waters around Broomes Island, the most severely depressed region of the estuary. This increase would maintain DO levels over 1 mg/l throughout the estuary for most of the critical summer period.

Future Strategies

The goal for phosphorus removal, as stated in the Patuxent Nutrient Control Strategy, has been met. When nitrogen removal at Western Branch becomes operative, the goals of the strategy for nitrogen removal will be met as well. However, management of nutrient discharges will not end. If the Patuxent watershed continues to experience growth similar to past years, sewage flows will increase. Nitrogen and phosphorus effluent concentrations must be reduced further to maintain the goals of the strategy and to accomplish the desired improvement of water quality in the Patuxent estuary.

Managing Living Resources

1989 STATE OF THE BAY

Bringing Back the Striped Bass

Not long ago, the striped bass or rockfish was the most popular commercial and sport fish in the Chesapeake Bay. Throughout the 1960s and early 1970s, commercial harvests of striped bass increased to record high levels. By the late 1970s, striped bass landings had begun an unprecedented decline. In response to the decline, this fish became the focus of increased monitoring and management in the Bay. Concern about the striped bass has also extended to the eastern seaboard states due to the fish's long migrations— ranging from North Carolina to Canada— and the extensive harvesting along this route. Scientists estimate, in some years, up to 90% of the east coast landings are from the Chesapeake Bay stock. The Bay, therefore, is a major focus of Atlantic coast management efforts.

Monitoring of Striped Bass

Scientists have monitored Chesapeake Bay striped bass stocks since the late 1800s. The earliest monitoring data were catch records collected primarily for economic purposes although catch data have also been used as a relative indicator of stock size.

Although catch statistics have been collected continuously for decades, they do not provide reliable information on the size of the stock or the causes of striped bass decline. Powerful economic, managerial, and technological forces influence the intensity of fishing and can bias the catch statistics relative to the actual number of fish in the population. Long-term monitoring programs, independent of commercial and recreational interests, allow scientists to track the status and trends of a fish population and evaluate the effects of fishing and environmental factors.

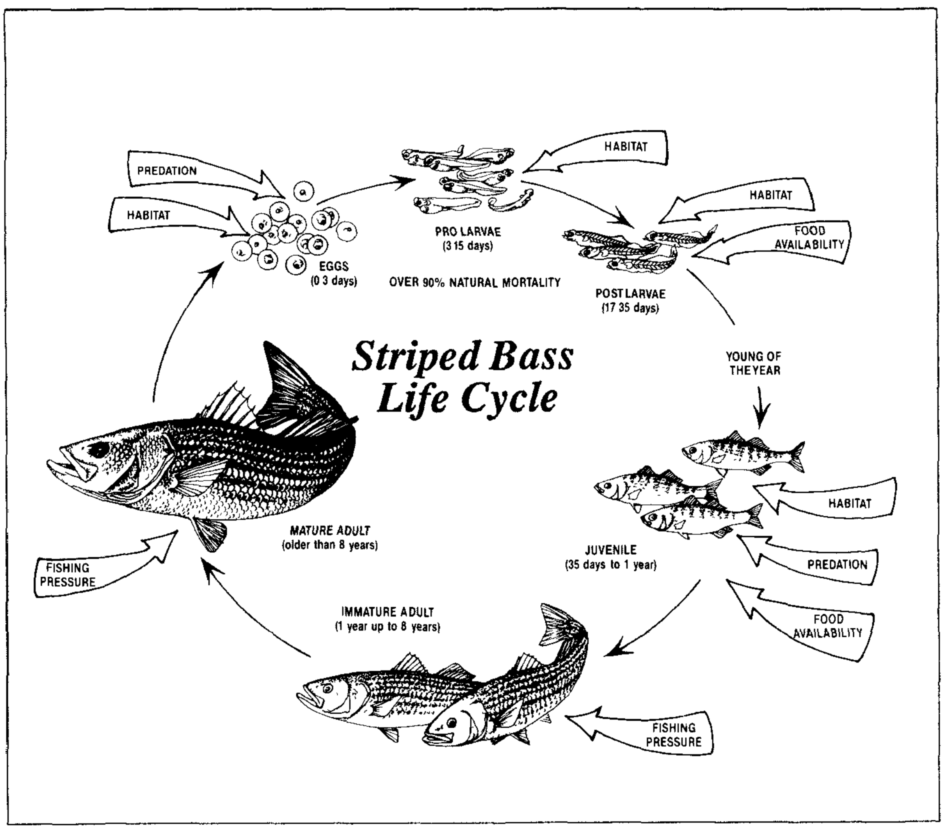


Figure 1: The life cycle of the striped bass including the approximate duration of life stages and major sources of mortality at each stage in the fish's life.

The Striped Bass Glossary

Larva: The immature form of an animal that is fundamentally different from its parent and must undergo metamorphosis before assuming adult characteristics.

Year-class: All of the fish born in a given year.

Juvenile: A striped bass younger than 1 year.

Recruitment: Those juvenile striped bass which survive to become adults.

Seine Survey: An annual assessment conducted by Virginia and Maryland to calculate the juvenile index. Large seine nets with floats and sinkers are drawn ashore, capturing a representative sample of the fish population.

In addition to determining the number of fish, monitoring programs often collect other valuable information such as sex, size and the number of eggs carried before spawning. Tagging fish has also proved useful in tracking bass migration patterns and estimating mortality. Striped bass are targeted for more comprehensive monitoring than any other Bay species.

Recruitment

One critical type of monitoring for the fishery determines the success of reproduction and subsequent recruitment into the adult population. This type of monitoring can help forecast the size of the population and evaluate the effects of habitat or water quality deterioration at the spawning sites. The oldest monitoring program of this type for striped bass is the beach seine survey. Scientists have used beach seines consistently since 1954 in Maryland and since 1967 in Virginia (excluding 1974-1979) to measure the abundance of each year's young striped bass.

Conducted in striped bass nursery areas during the summer, the survey counts juveniles that have grown to about 2 inches since hatching in the spring. Once at this juvenile stage, One of the most widely recognized indices of finfish recruitment, the juvenile striped bass index, has been used for over 35 years as a predictor of both striped bass commercial harvests and Chesapeake Bay stock size. Using seine nets, scientists sample major spawning and nursery areas to assess the abundance of each year's class of young striped bass. The index is merely the average number of juvenile fish caught in each haul of the net. Collected each year the indices are important aids in determining population trends for the striped bass. Managers can then use this information to establish wise management strategies.

environmental threats to the survival of striped bass diminish and the seine survey is able to accurately reflect the success of each year's spawn. Maryland's familiar "juvenile index" is the annual average number of juvenile fish caught during the seining of four major spawning and nursery areas (the Choptank, Nanticoke and Potomac rivers and the head of the Bay). Virginia surveys generate similar statistics for the York, Rappahannock and James rivers (Figure 2).

More recent recruitment monitoring programs sample in the spring when mortality is highest and the concern for water quality impacts is greatest. During this period, scientists collect striped bass eggs and larvae with fine mesh nets in some major spawning areas to assess the abundance and survival of the fish during the vulnerable early life stages. These programs often include simultaneous water quality sampling to examine the factors that enhance or reduce survival during these stages. Scientists have also used bioassays (toxicity studies) extensively to measure the survival of striped bass larvae in their natal waters.

Management Actions

In accordance with the Atlantic Interstate Fisheries Management Plan, Maryland implemented a fishing moratorium on striped bass for Maryland waters in 1985. Virginia and the District of Columbia followed suit in 1989. Other Atlantic Coast states have imposed minimum and maximum size limits, gear restrictions, creel limits and closed seasons. As of June 1989, Virginia, D.C. and the Potomac River Fisheries Commission banned all striped bass fishing for at least one year. These actions are designed to ensure that at least 95% of the females from the 1982 and future year classes will spawn at least once before joining the exploitable population. The stringent management actions have eliminated the immediate danger to striped bass stocks from overharvesting. Figure 3 demonstrates the effect of protecting the recent year classes. Striped bass from the protected year classes greatly outnumber those exposed to heavy fishing pressure.

In recent years, traditional striped bass spawning areas in Maryland have shown below average spawning success. Production of young striped bass in the Maryland Bay in 1989, however, is dramatically improved over the previous seven years. In recent years, juvenile indices have been at record highs in Virginia Bay waters.

Studies in the Choptank River have shown that poor water quality can increase the mortality of larval striped bass. This effect intensifies at low stock levels. Poor water quality in the spawning areas is due to contaminants carried from the land and atmosphere by rain. Acid deposition has been implicated in the acidification of spawning habitats and the mobilization of certain contaminants. Concern about acid rain's effects on striped bass and

The impressive results of fishing for striped bass at the Chesapeake Fishing Fair in the mid-1950s.

other fish species was a major reason behind Maryland's call for national legislation to reduce acid rain.

The wide annual variations in juvenile indices are related both to environmental factors and to the variable quantity of eggs produced by mature females. Acceptable environmental conditions and sufficient egg deposition should result in increased numbers of young striped bass in the Chesapeake Bay.

Historical Juvenile Indices for Striped Bass

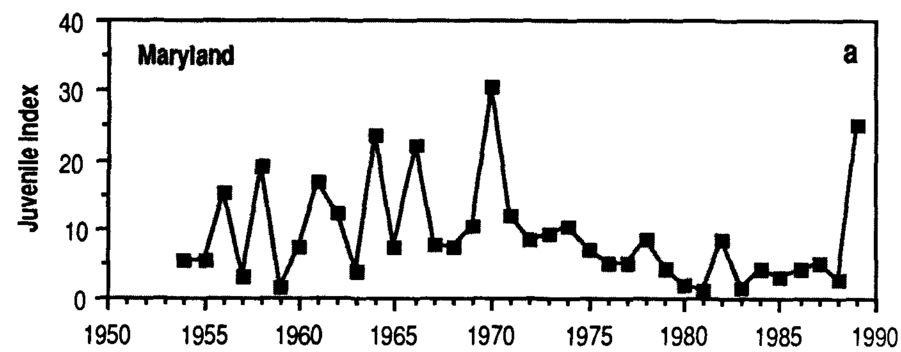
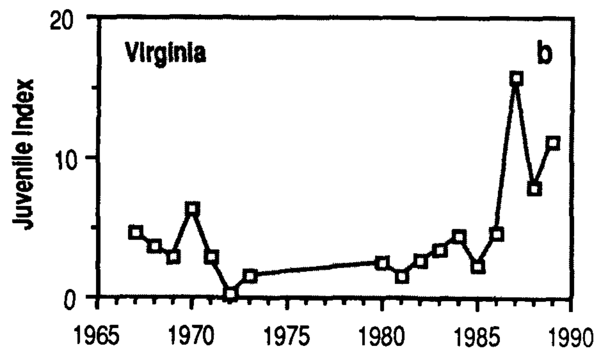


Figure 2: Maryland's juvenile index, with the exception of an average 1982 year class, has remained near the lowest recorded levels throughout the 1980s. This year, 1989, has an index of 25.2, due to spawning by the protected 1982 year class. Virginia's index has increased steadily since 1981, reaching a record high in 1987. The two indices, while similar, are not precisely comparable.



Ages of Female Striped Bass Upper Bay - Spring 1988

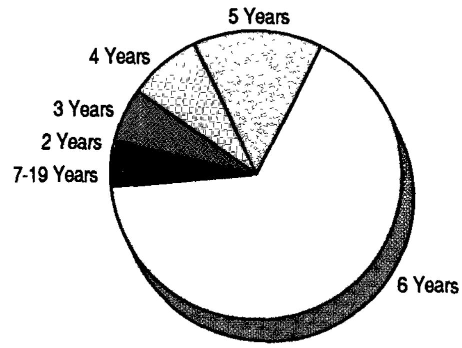


Figure 3: In the spring spawning season of 1988, the 6-year olds (1982 year class) constituted the largest portion of the female striped bass population in the upper Bay. Managers and scientists designed the Maryland moratorium and other restrictions by Atlantic coast states to protect this group of females until 95% had spawned.

To augment the management actions implemented under the Interstate Fisheries Management Plan, Maryland and the U.S. Fish and Wildlife Service (USFWS) began a stocking program in 1985. The purpose of the program was to supplement the Maryland spawning stock of striped bass using hatchery reared fish. In 1985, the two agencies stocked more than 370,000 striped bass in the Bay. In 1986, Virginia entered into a similar agreement with the USFWS and by 1987, the number of stocked fish rose to 801,341, with most of the increase coming from Bowden National Fish Hatchery and two electric utility companies (BG&E and PEPCO). All stocked fish have received coded wire tags for use in a tag recovery program.

Signs of Success

During the late 1970s, commercial and recreational harvests of striped bass dramatically deteriorated. According to the Emergency Striped Bass Research Study produced by USFWS and the National Marine Fisheries Service in cooperation with state agencies and universities, "Reductions in harvest levels can be attributed principally to a decline in production of juveniles by the Chesapeake Bay stock." The decline in juvenile production can be attributed to either long-term overfishing, long-term decreased larval survival rate, or a combination of these two factors. The availability of reliable monitoring data was critical in identifying the problem and implementing the necessary management actions.

Due to these recent management actions, the striped bass seems to be maintaining high numbers from each year class as documented by the monitoring programs. Striped bass commercial landings, however, no longer give even a rough assessment of stock size since fishing regulations have been modified to protect the existing stocks. As a result, long-term monitoring and tagging studies must continue to assess accurately the response of the population to management actions and to gauge the health of the stocks. The 1989 beach seine survey was sufficiently high in Maryland to reach the three-year average required to permit a highly restricted commercial and recreational catch of striped bass in fall 1990. Virginia is also proposing a restricted season.

We are now about to enter a crucial period since the majority of the protected 1982 year class has spawned in the Chesapeake Bay. By monitoring the recruitment from this more abundant year class in conjunction with comprehensive water quality monitoring, scientists can work toward establishing a link between potential water quality problems and spawning success. This new monitoring information is eagerly awaited and will contribute significantly to continued management success in restoring the striped bass population.

Plight of the Oyster

Oyster abundance in Chesapeake Bay is at its lowest level in history. Scientists estimate populations are no more than 1% of historical levels—threatening the loss of a valuable resource and a symbol of the Bay's productive fisheries. This continuing decline of the oyster not only symbolizes the Bay's problems but quite literally exacerbates the current problems of degraded water quality and habitat loss.

The deterioration of the Bay's oyster population is a complex problem. Recent outbreaks of parasitic infection, poor reproduction, reduced survival of larvae and young oysters, loss of habitat due to sedimentation and anoxia and commercial overharvesting all have played a role. At the same time, while oyster parasites have spread to new territory resulting in unprecedented infection rates, increases in market price have spurred greater fishing effort in areas with surviving oyster stocks.

The loss of oyster populations has been most severe in regions with salinities over 12 parts per thousand (ppt). Only small areas, mostly near the upstream limits of oyster habitat in the tributaries, now have parasite-free oyster stocks. Loss of large harvestable areas has forced the watermen to congregate in less afflicted areas. In Virginia, for example, most watermen have shifted their harvesting to the James River beds.

The Deadly Parasites

In 1957, scientists first observed MSX (*Haplosporidium nelsoni*), a lethal parasite of oysters, in Delaware Bay. Three years later MSX was found in Chesapeake Bay where it moved progressively northward. Since then, changes in freshwater flow and salinity caused the parasite to disappear, then reappear, in the Maryland portion of the Bay. Until the mid-1980s, distribution of MSX in Virginia remained stable; three successive years of drought starting in 1986, however,

Decline of the Oyster in Chesapeake Bay

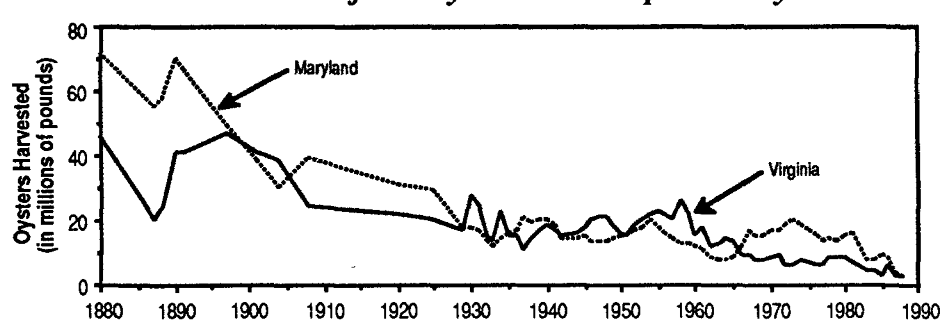


Figure 4: Harvests of oysters in Maryland have shown a steady decline since the late 1800s. Estimates of the mid 1880s Maryland harvest run upwards of 70 million pounds. Even back then, the Federal government was concerned that watermen were overfishing the state's oyster beds. Overall, Virginia harvests have also declined consistently throughout the same period of time.

spurred rapid spread of the parasite in many areas that had been most productive during the previous two decades.

"Dermo" is the colloquial name for the infection caused by another deadly oyster parasite—*Perkinsus marinus*. First observed in the Chesapeake Bay in the late 1940s, Dermo is currently found in most of the oyster-growing areas of the Bay. Dermo does not kill oysters as rapidly as MSX, but the infections are more persistent. Over the long-term, it has likely done more damage to oysters than MSX. In 1988, much of the oyster mortality caused by parasites has been attributed to Dermo.

Despite research efforts, key mechanisms in the epidemiology of MSX and Dermo remain poorly understood. Consequently, the ability to combat or avoid parasite mortality is limited. Scientists know little about how these parasites infect oysters or what environmental conditions relate to their pathology. MSX causes high mortality rates in oysters only in more saline waters (> 12 ppt), but year-to-year fluctuations in MSX occurrence and virulence remain a mystery. Even less is known about Dermo; this parasite seems to infect oysters at all salinities and is more chronic than MSX.

Recruitment into the Ranks

Each fall, scientists measure the recruitment or yearly production of young oysters to the population by counting the number of spat per bushel of shell on natural oyster bars. In

> The uncertain status of the oyster in the Chesapeake is not new. As early as 1889, Encyclopedia Brittanica contained a long treatise on the immense value of this bivalve and the potential for its destruction through overfishing. "The oyster fishery is everywhere, except in localities where the natural beds are nearly exhausted, carried on in the most reckless manner, and in all directions oyster grounds are becoming deteriorated, and in some cases have been entirely destroyed."
>
> This concern was justified. In Maryland and Virginia, watermen harvested over 115 million pounds of oysters in 1880, worth almost $7 million. Oystering was the largest of all fishing industries "yielding products three times as valuable as those of the cod fishery and six times those of the whale fishery." Although oysters came from many coastal states in the U.S., the Chesapeake Bay supplied 80% of the total yield.

Oyster Spat Indices

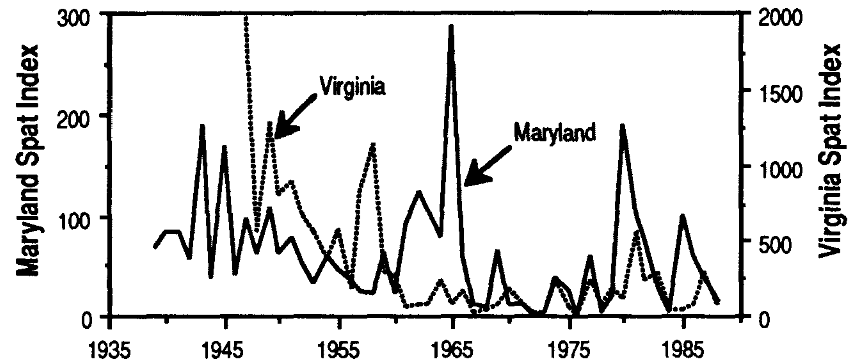


Figure 5. The oyster spat index, the average number of young oysters found on a given amount of dredged shell, shows a significant natural variability. From the 1930s through the present, however, the average spat index has declined. Reproductive success must increase if the oyster population is to rebound.

Virginia, these counts are repeated in the spring. Averaging the spat counts over a large group of selected oyster bars gives a numerical index of the strength of each year class. Over the past years, these indices of recruitment have shown a long-term decline. Determining whether the spatfall declines are related primarily to declines in oyster stocks or to other environmental conditions is a critical research question.

Spatfall has decreased steadily since 1985 and is still concentrated in areas where the parasite is endemic. The prospects of spat surviving in these parasite-ridden areas for 3-5 years, when they will reach marketable size, are poor. In areas with good strikes but poor probability of survival in Virginia, young oysters are transplanted to lower salinity zones where parasites cannot survive or their growth is slowed and the oysters can reach harvestable size.

Oysters and the Environment

The American oyster is an extremely hardy animal under most conditions, thriving over a wide range of salinity, temperature and geographical area. Adult oysters are resistant to high levels of many contaminants, including heavy metals, and can also survive the complete absence of dissolved oxygen for a few days.

Probably the greatest environmental threat to oysters is sediment. Large quantities of suspended sediment interfere with normal feeding. When sediment settles to the bottom, it may smother oysters if their growth does not outpace the sedimentation rate. Most

Hand tongers working the oyster beds at the mouth of the Severn River in the mid-1950s. They are standing on a Dead Rise boat, the standard Bay oyster boat.

MSX-Free Oyster Habitat Zones

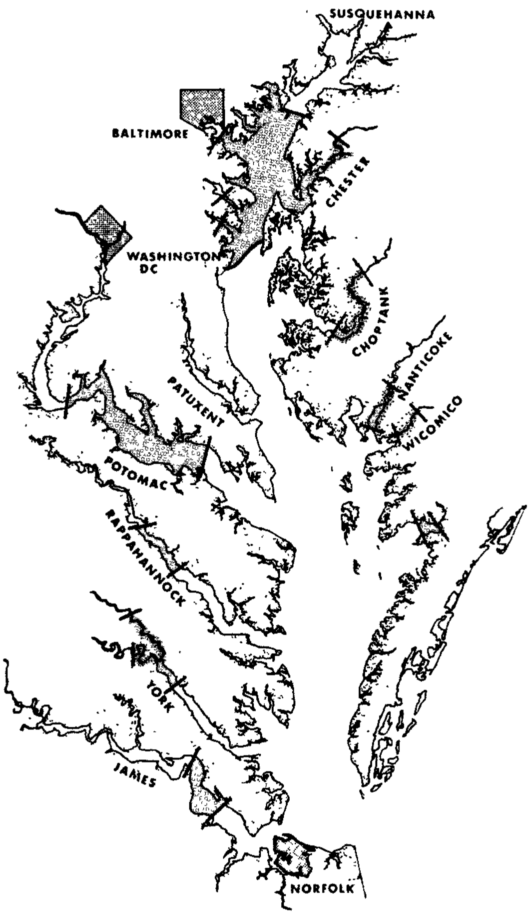


Figure 6. The areas shaded on the map have average salinities between 5 and 12 parts per thousand (ppt). MSX infections cause oyster mortality only above 12 ppt. Oysters generally do not live in waters fresher than 5 ppt. Current and future management will focus on these shaded areas where the prospects for oyster survival are better.

Dermo infections do not appear to be limited by salinity. The 12 ppt isohalines were drawn from 1985 (average year) monitoring data and the 5 ppt isohalines from average summer predicted conditions *(Corps of Engineers Low Flow Study, 1982).*

important, a fine layer of sediment on hard cultch (material, such as shell, to which oysters attach) prevents spat from attaching. A successful spat set can be destroyed in the first few days if covered with a layer of sediment. Sedimentation can be caused by winds and waves stirring up the bottom, heavy rainfall with sediment runoff from cleared land, dredging or other physical disturbance to the bottom, shoreline erosion and decaying algal blooms.

Scientists think that dissolved oxygen depletion (hypoxia) may have destroyed oyster bars in some parts of the Bay and its tributaries. Oyster bars tend to occur along the upper flanks of deep channel areas. Hypoxia develops seasonally in deep waters when the Bay is stratified (cool, salty water at depth and warmer, fresher water near the surface); under certain conditions, this deep hypoxic water can move into the shallower waters. If hypoxia is sufficiently severe and persists long enough over the beds, adult oysters and the associated community may die. Hypoxia also may prevent larval settlement and recruitment to affected oyster bars. Even without physical intrusion of low oxygen water, the shallows may occasionally become hypoxic due to local eutrophication.

Although they are tolerant of some types of pollutants, oysters have been threatened in recent years by the use of tributyltin (TBT) in boat bottom antifoulant paints. TBT causes grotesque shell deformities and is extremely toxic to oyster larvae. Severe restrictions by the states on the sale and use of TBT paints have reduced the potential for harm, but TBT and related compounds are still found in the environment and oyster tissue (see section on TBT).

Oysters and the Ecosystem

When abundant, as they once were in the Bay, oysters play at least two dominant ecological roles. First, large populations of these bivalves filter immense quantities of water. Scientists estimate that prior to heavy exploitation by man, oysters filtered the entire volume of the Bay in only a few days.

Much of the suspended matter was removed by oyster filtration, greatly reducing algal concentrations. The increased light penetration, curtailment of the plankton population and high rates of dissolved and particulate waste production by oysters likely had profound effects on the ecosystem. The particulate wastes helped to nourish bottom-dwelling deposit feeders while dissolved wastes resupplied nutrients to the algae. The nature of these effects on the whole ecosystem can only be surmised; our remnant oyster population now requires more than a year to filter the entire volume of the Bay.

The other important ecological role for oysters is a by-product of their hard shells. These shells act as platforms for many organisms including barnacles, mussels, anemones, sponges, worms and tunicates. Like oysters, most of these animals are filter feeders and their abundance amplifies the effects of oyster filtration described above. Man has created substitute habitats for some of these creatures by building piers, bulkheads and revetments. It is unlikely, however, that manmade structures have fully replaced either the quantity or quality of habitat once provided by the oyster bars.

The Outlook for the Oyster

The states have invested substantial amounts of money and effort into maintaining harvestable stocks of oysters through seed and shell repletion programs. In the seed programs, juvenile oysters are collected where they are abundant but cannot grow well and move them to areas where they are able to grow rapidly and are harvestable after 2-3 years. Under shell repletion programs, oyster shells dredged from buried oyster bars or taken from packing houses are placed on top of natural oyster bars to maintain the hard bottoms which favor spat settlement. Oyster management also entails seasonal closures, gear restrictions, catch limits and restrictions on the hours of fishing. Leasing programs permit individuals to reserve areas of the Bay bottom for private culture of oysters.

Despite these management efforts, oyster harvests have continued to decline. There are no methods presently available to prevent the loss of stocks to the parasite. When a severe outbreak of MSX struck Tangier Sound in 1963, there were no harvestable oysters for at least 5 years. It was almost 10 years before the yield approached economically attractive levels, yet oyster densities in this area never returned to pre-parasite levels.

Scientists hope that a combination of genetic research and natural immunity eventually will lead to more parasite-resistant stocks. Developing widespread immunity to MSX and Dermo in the Bay's natural oyster population, however, is a long-term prospect. On the positive side, commitments to improve water quality and environmental management in Bay watersheds offer the promise of more and better oyster habitat. The baywide management plan for oysters, completed in July 1989, provides an opportunity for Maryland and Virginia to plan jointly for the future of the oyster.

Oystering has been a traditional way of life and a means of support for many people and communities around the Bay. Just as important, oysters were once dominant members of the Bay ecosystem, providing many other species with a way of life. Rebuilding oyster populations will be one of the toughest challenges in the work to restore the Chesapeake Bay.

The SAV Link

Submerged aquatic vegetation—a distinctly sterile name for a set of plants that shelters a profusion of life. These plants are key elements in the restoration and maintenance of the Bay's health. One of the most alarming trends, therefore, over the past few decades has been the decline of the submerged aquatic vegetation (SAV) beds that once flourished in the Bay. The rapid loss of these plants prompted the scientific community to study the problem, search for causes and propose solutions. The scientists discovered that all species of the aquatic plants were affected and the loss was occurring throughout the Chesapeake Bay. More importantly, the decline was not due to a single factor but to overall deterioration of Bay water quality.

Aquatic Grasses

An essential link in the food web, SAV is a food source for many species of waterfowl, fish, shellfish and invertebrates. The plants provide habitat and shelter for a variety of Bay species. Fish utilize the beds as nurseries, receiving protection from predatory fish. Crustaceans, such as the blue crab, hide among the grasses during their vulnerable molt.

While providing an invaluable source of food and cover for many Bay species, SAV also maintains the integrity of the surrounding shallow water habitat. SAV photosynthesis helps to oxygenate Bay water. The plant leaves baffle water currents, allowing suspended sediment particles to settle out of the water. The root systems bind the substrate and reduce sediment resuspension while large, dense beds dampen wave energy and slow shoreline erosion. Most significantly, in a system plagued with excess nutrients from urban, suburban, and agricultural sources, the ability of SAV to take up nutrients during the spring and summer helps to retard eutrophication of the Bay waters.

With rapid development around the Bay and increased use of the Bay, SAV not only decreased drastically in abundance but also changed in species composition. The species shifts have important implications for the animals inhabiting the Bay. In some cases, non-native species such as Hydrilla or water chestnut may take over a portion of the Bay or tributary, reducing the local diversity of plants. As diversity drops, the diversity of animals that can live in the SAV habitat also declines. Waterfowl, in particular, are highly dependent on certain types of SAV for their food supply.

Susquehanna Flats is an area which suffered serious declines and species changes—then was repopulated by some native species. In the late 1950s and early '60s, many native grasses suffered while the introduced Eurasian watermilfoil spread. Although some native species recovered during the 1960s, almost all the SAV disappeared in the '70s. By the mid-1980s, SAV returned with the resurgence of wild celery and other native species. The return of these grasses bodes well, for along with the SAV will undoubtedly come a variety of other animal and plant life.

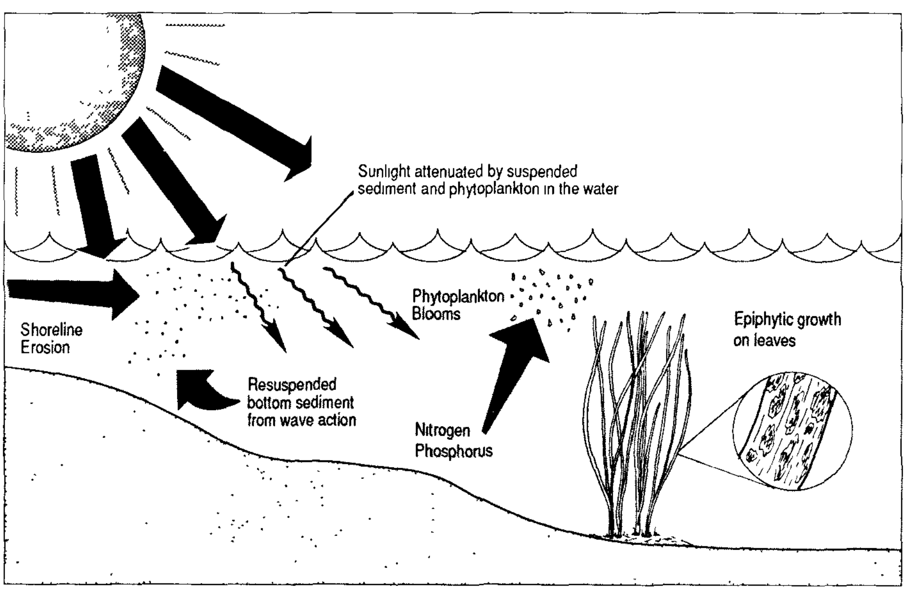


Figure 7. Bay scientists have linked reduced light availability to the baywide decline of the SAV beds. Reduced sunlight penetration, due to excessive phytoplankton and suspended sediment, results in less available light energy needed for photosynthesis.

Since these plants play an integral role in the healthy functioning of the Bay, researchers have monitored the dwindling of SAV since 1971. Annual ground surveys by the Maryland Department of Natural Resources at over 600 sites showed a steady decline of SAV in Maryland waters. The percentage of vegetated sites decreased continuously from 28.5% in 1971 to a mere 12.3% in 1977.

In 1978, researchers conducted the first baywide survey of SAV using aerial photography. The photographs revealed that SAV covered 41,110 acres of Chesapeake Bay bottom. By 1984, this figure had dropped to 38,053 acres although by 1987 it had increased to 49,714 acres. Although the slight increase is encouraging, the current population does not approach the 100,000 to 300,000 acres estimated for the mid-1960s.

The Cause of SAV Decline

In the late 1970s and early 80s, researchers at the University of Maryland and the Virginia Institute of Marine

Science (VIMS) began to unravel the reasons behind the grasses' decline. They focused on those environmental factors affecting plant growth, including processes such as eutrophication and sedimentation which decrease light penetration into the water (Figure 7). They also studied the effects of toxicants, especially herbicides, to which the SAV may have been exposed.

When nutrient (phosphorus and nitrogen) concentrations are too high, phytoplankton bloom in the water and epiphytes (plants which live on the surface of other plants) grow on the SAV. The phytoplankton cloud the water, diminishing light reaching the grasses. The epiphytes further lessen available light. These stresses reduce the depth at which SAV can live, restricting growth to shallow water where increased wave energy, erosion and grazing by waterfowl further stress the plants. In some cases, the stress becomes overwhelming and the grasses are completely lost.

As sediment washes into the Bay, it also restricts light penetration. Although some silt and clay is needed to create a suitable substrate for the plants to root, excessive particulates in the water significantly lessen water clarity. Poor agricultural practices and accelerated land development have introduced a sediment overload. Runoff carries this sediment into the water, where the particulates may remain suspended long enough to reduce sunlight reaching the plants.

Researchers also examined agricultural herbicides, such as atrazine and linuron, for their effects on SAV growth. At high concentrations, 50-100 parts per billion (ppb), atrazine severely reduces photosynthesis by SAV and complete recovery may not be possible. Five to 10 ppb produced a 10-20% loss of photosynthesis. Surveys since 1977 have not found concentrations over 20 ppb; even with concentrations of 10-20 ppb, however, the plants took 1-4 weeks after the initial exposure to fully recover. If the interval between exposures is shorter than the plants' recovery time, then photosynthetic impairment may persist. The researchers concluded that these herbicides alone did not cause the SAV decline but, in combination with other environmental stresses, certainly contributed.

Monitoring SAV Habitat

In the 1980s, the search for the reasons behind SAV loss moved from the laboratory into the field. To verify the links among excessive nutrients, suspended sediment and diminished light, and to evaluate the impact of other physical factors (such as wave action) affecting SAV growth, researchers set up nearshore habitat monitoring programs.

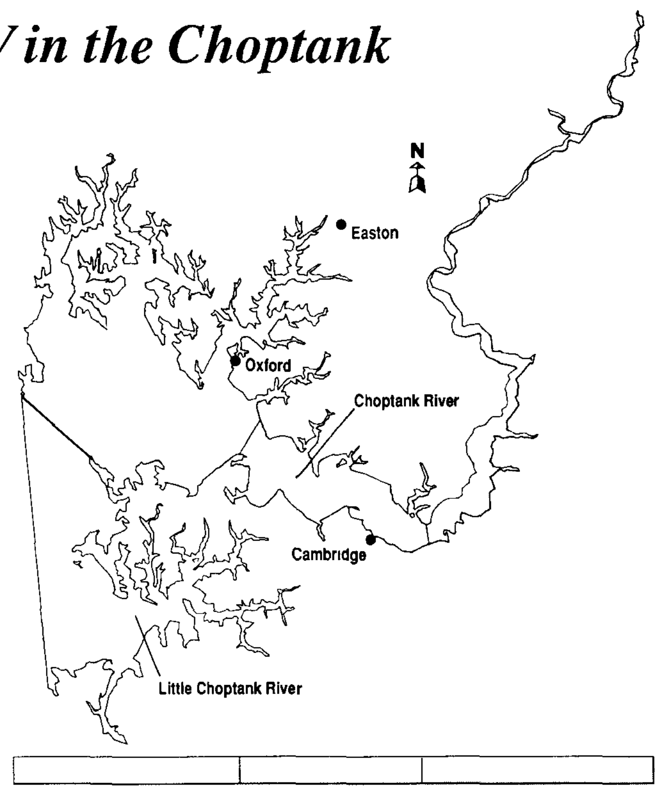
Scientists at Harford Community College began to monitor shallow water habitats on the Susquehanna Flats and in the surrounding tidal tributaries in 1985. The vast beds of SAV that once covered the Susquehanna Flats, prime habitat for migratory waterfowl, all but disappeared in the late 1960s and early 1970s. Water quality monitoring in vegetated and unvegetated areas of the upper Bay was combined with SAV transplanting to define the habitat requirements of tidal-fresh SAV species. After more than three years of monitoring, the relationship among SAV, nutrients, sediments and light levels is emerging.

Key questions concerning the occurrence of high nitrogen concentrations with low phosphorus levels and the impact these have on SAV in tidal fresh areas are being addressed as part of a baywide analysis of all SAV habitat monitoring data within the next year. Habitat monitoring data from the upper Bay and the Potomac River will be instrumental in answering these remaining nutrient limitation questions.

In the Potomac River, the U.S. Geological Survey has monitored water quality status and trends since 1978 when SAV was completely absent in

Figure 8

SAV in the Choptank



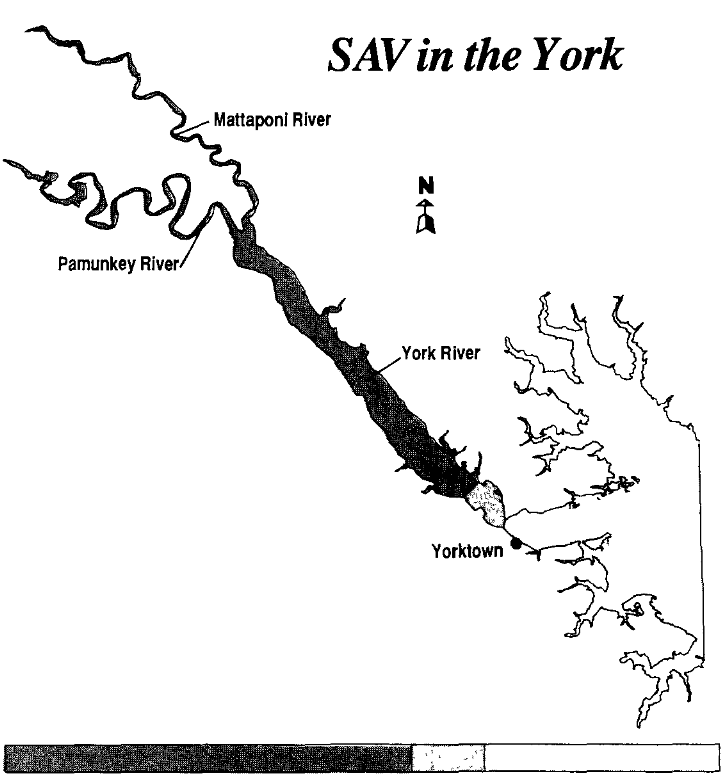
SAV Abundance[1]	Resurgence of SAV	Marginal SAV	SAV Absent
Chlorophyll *a* (µg/l)[2]	2.4 - 10	3.0 - 15 0	4.0 - 29.0
Dissolved Inorganic Nitrogen (mg/l)	0.04 - 0 10	0 03 - 0.14	0.02 - 0.36
Dissolved Inorganic Phosphorus (mg/l)	0 002 - 0 007	0.003 - 0.008	0.01 - 0.05
Light Attenuation (m^{-1})	0.8 - 1 2	1.0 - 1.9	1 7 - 5.0
Secchi Depth (m)	1.4 - 2.1	0.9 - 1.7	0 3 - 1.0
Transplant Success	Good	Temporary	None
Total Suspended Solids (mg/l)	3 0 - 13.0	6.1 - 22.0	9.2 - 32.0

1 Primarily widgeongrass (*Ruppia maritima*)

2 Ranges of annual growing season (April - Sept) medians for surface samples from nearshore stations in each section (1986-1988)

Figure 9

SAV in the York



SAV Abundance[1]	SAV Absent	Marginal SAV	Resurgence of SAV
Chlorophyll *a* (µg/l)[2]	2 4 - 19 7	2 9 - 12 5	2 1 - 10.7
Dissolved Inorganic Nitrogen (mg/l)	021 - 25	028 - 15	.022 - 11
Dissolved Inorganic Phosphorus (mg/l)	023 - 050	015 - 040	010 - 027
Light Attenuation (m-1)	1.35 - 2 19	1 32 - 1 40	0 73 - 1 23
Secchi Depth (m)	0 8 - 1 3	1.2 - 1 3	1 4 - 2 3
Transplant Success	None	Temporary	Good
Total Suspended Solids (mg/l)	9 7 - 22 3	10 4 - 19 2	4 7 - 13 5

1 Primarily eelgrass (*Zostera marina*), some widgeongrass (*Ruppia maritima*)

2 Ranges of annual growing season (spring and autumn) medians for surface sample from nearshore stations in each section (1985-1988), only one station (Mumfort Island) in 'marginal zone' before 1988

the upper Potomac. The USGS continued monitoring through 1988 when vegetation extended from the District of Columbia south to Quantico, Virginia. The USGS is analyzing this 10-year data set, which captured the "before, during and after" water quality conditions associated with the reestablishment of SAV in the Potomac, to develop habitat quality requirements.

Researchers at the University of Maryland's Horn Point Environmental Laboratory initiated a similar program in the Choptank River. The 4-year water quality monitoring program has documented habitat quality patterns within the Choptank's nearshore environments (Figure 8). In the lower river, decreased nitrogen and phosphorus levels coincided with healthy SAV beds, survival of the transplanted SAV and successful natural revegetation. In the less saline water, diminished water quality reduced SAV distribution and abundance; transplanting success was marginal. In the oligohaline (0.5-5 ppt) and tidal fresh reaches of the river, high nutrient and chlorophyll *a* concentrations and reduced light levels were matched by the absence of SAV beds and the failure of all transplants.

Scientists at VIMS began detailed investigations of the relationships between environmental quality and the growth of the two primary SAV species in the lower Chesapeake Bay—eelgrass and widgeongrass— starting in the 1970s. A biweekly sampling program, initiated in 1985, focused on the shallow water habitats of the York River to monitor environmental quality along an upriver gradient: from the lower river which currently and historically supported viable SAV beds to the upper reaches devoid of SAV (Figure 9).

The unvegetated upriver stations had consistently high nutrient concentrations and turbidity levels. A downriver gradient of improved water quality matched increasingly abundant SAV beds in the shoal waters of the York River. Survival of transplanted eelgrass, planted each fall to determine the potential for SAV growth, production and survival at the sites, closely coincided with the water quality gradient.

Results from the York River SAV habitat monitoring program are providing insights into the habitat quality requirements of the Bay's SAV species which live in high salinity areas. The response of the plants in these areas has been different from low salinity species in terms of their relative tolerance of nitrogen and phosphorus concentrations. The habitat quality requirements being developed for these lower Bay species should be transferable to other high salinity areas of the Bay where the same species were present historically.

Habitat Requirements

Current research programs focus on the distribution and abundance of SAV, assessment of transplanting methods and intensive water quality monitoring of nearshore habitats. These programs are providing quantitative habitat quality requirements for various SAV species. The Bay Program published an initial list of SAV habitat requirements for high salinity zones in the "Habitat Requirements for Chesapeake Bay Living Resources."

A set of requirements for the tidal fresh and oligohaline salinity zones is not yet established. Researchers are now developing the requirements for these zones. Once determined, programs can address habitat problems in those watersheds exceeding established requirements. In addition, regional restoration goals can be set for SAV acreage, abundance and species diversity considering historical abundance, distribution records and potential habitat.

The growth and survival of SAV is intricately tied to the water quality of the Chesapeake Bay, making it a valuable indicator of an area's ability to support living resources. Attempts to improve Bay water quality can be evaluated by monitoring the response of SAV to modifications of habitat quality. Changes in SAV distribution and abundance ultimately serve as a measure of baywide restoration.

Toxicant Case Studies

1989 STATE OF THE BAY

The TBT Problem

Within the past two years, tributyltin has become part of the vocabulary of many boat owners, marina operators, scientists and government agency personnel. Tributyltin or TBT provides an important case study where the Chesapeake Bay Program's monitoring efforts directly influenced state and national TBT legislative and regulatory decisions. TBT is the first example in which the government restricted use of a pesticide based solely on the risk to the environment—not human health.

Tributyltin was most commonly used as an additive to boat bottom paint, preventing the undesirable growth of barnacles, tubeworms and other fouling organisms. Industry also used TBT as a stabilizer in the production of PVC pipes, paper and textile fungicides, industrial cooling water biocides, household disinfectants, agricultural pesticide products and as a catalyst in many other chemical processes. Approximately 624,000 gallons of antifouling paint, containing an estimated 1 million pounds of TBT compounds, were sold annually nationwide. The major use of TBT paint was for ships and boat hulls with less than 4% used on docks, buoys, crab pots and fish nets. In the Bay, leaching of TBT from boat bottoms posed the greatest potential threat given the direct exposure of vulnerable organisms to the pesticide.

By 1985, scientists began to report lethal and chronic effects of TBT exposure at concentrations in the low parts per trillion (pptr). Finfish larvae were found to be sensitive at parts per billion (ppb) levels of TBT. Scientists documented unnatural shifts from female to male gender in one species of snail exposed to less than 20 pptr. At the same time, managers undertook efforts to assess the need for restrictions in the use of TBT as a boat bottom antifoulant.

In January 1986, the Environmental Protection Agency initiated a special review of TBT used as an additive to antifouling boat bottom paints. Maryland and Virginia had already begun efforts to monitor TBT levels in the Bay. Given the Chesapeake Bay Program's interest in the issue and a growing data base on TBT concentrations throughout the Chesapeake Bay, EPA undertook an intensive survey of several Bay harbors. The EPA's Chesapeake Bay Liaison Office convened a TBT workgroup to assist in the survey design and to coordinate Bay monitoring and research in support of the TBT legislative and regulatory decisions under consideration at the state and national levels. Representatives from Maryland and Virginia state agencies, research scientists from the Virginia Institute of Marine Science(VIMS) and Johns Hopkins University, the Navy and EPA composed the workgroup.

TBT Timeline

Early 1980s — Scientists begin to actively test the toxicity of TBT; first reports of visible impacts of TBT on adult oysters in Europe.

May 1985 — Navy supports intensive survey of Back Creek.

September 1986 — EPA completes intensive survey of four northern Bay harbors.

July 1987 — Governor Schaefer signs Maryland's TBT legislation into law.

June 1988 — Virginia adopts TBT water quality standard effective September 1988.

June 1988 — President Reagan signs into law the "Organotin Antifouling Paint Control Act of 1988."

June 1989 — EPA publishes draft water quality criteria for TBT.

1989 — Maryland to adopt TBT water quality standard.

1989-1990 — EPA to receive additional data from 1986 Data Call-In from manufacturers.

Early 1960s — TBT first registered and used as an additive to antifouling boat bottom paint.

Mid 1980s — Scientists report measurable effects of TBT at the low parts per trillion level.

July 1985 — Maryland initiates one-year TBT survey program; EPA initiates special TBT review.

March 1987 — Governor Baliles signs Virginia's TBT legislation into law.

October 1987 — EPA publishes preliminary determination to cancel certain TBT registrations and reclassify TBT antifouling paints as restricted use pesticides.

September 1988 — EPA publishes regulations cancelling/restricting continued registration and use of TBT products used as boat bottom antifoulants.

1989-1998 — National TBT monitoring program.

June 1993 — EPA to report to Congress on effectiveness of existing laws.

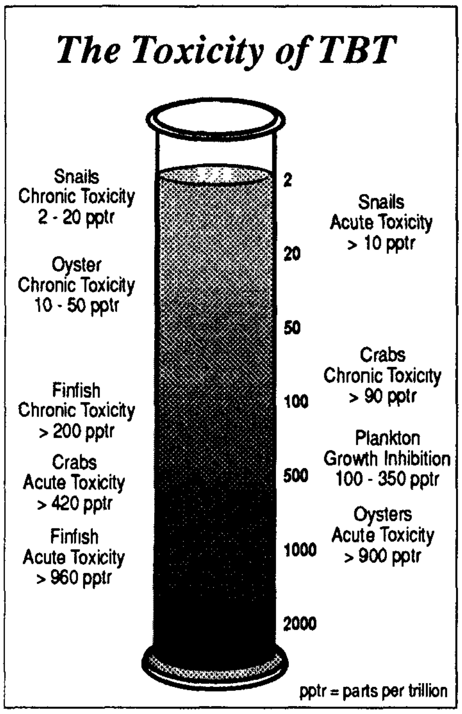
Monitoring Program Response

Maryland funded Johns Hopkins University (JHU) to monitor TBT concentrations monthly at 8 stations located in the northern Chesapeake Bay for one year (July 1985-June 1986). With continued support from the Navy and Maryland, JHU scientists initiated an intensive boating season survey of Back Creek, Annapolis, Maryland in 1986, resampling in 1988 and 1989. Virginia supported efforts by VIMS to begin a long-term TBT monitoring program on Sarah Creek (tributary to the York) and Hampton River (tributary to the James). The program, initiated in January 1986, includes monthly sampling of 8 stations. The Navy also conducted its own limited sampling of the Norfolk/ Elizabeth River harbor area in 1984. EPA funded and carried out an intensive survey of TBT levels in 4 harbors (Spa Creek, Solomons Harbor, Oxford Harbor and Plaindealing Creek) located in northern Chesapeake Bay during the 1986 boating season.

TBT in Chesapeake Bay

Figure 1 summarizes data from the 1984 to 1988 Chesapeake Bay TBT monitoring and survey programs. It shows the ranges of TBT concentrations from the single or combined sets of sampling locations versus indicators of toxicity or potential impact from exposure to TBT. EPA has posted a chronic water quality criterion for TBT of 26.4 pptr for freshwater and 10 pptr for saltwater. Respective acute water quality criterion are 10 and 26.6 pptr. Chronic toxicity causes impairment or abnormalities; acute toxicity is lethal. The ranges of TBT concentrations and total average concentration for most of the listed sampling sites are greater than the EPA chronic water quality criteria. Concentrations at many of the sites were high enough to potentially inflict chronic impacts on local mollusk and plankton communities.

Many of the sites sampled in Maryland waters were harbors with busy boat traffic and marina activities. TBT



concentrations at these sites averaged well above the EPA water quality criteria for protection against sublethal effects. At the remaining sites, with waters less impacted by boating and marinas (Plaindealing Creek and the Choptank River), no TBT was detected. TBT concentrations ranging from 20-24 pptr, however, were measured in the Potomac River.

The range and average concentration of TBT for individual sites directly reflect boating activity levels in the immediate vicinity (Figure 1). Even within a harbor, there is a gradient of TBT concentration from "upstream" areas of concentrated boating activity towards the adjacent tidal river, again reflecting the correlation of boating with TBT concentration.

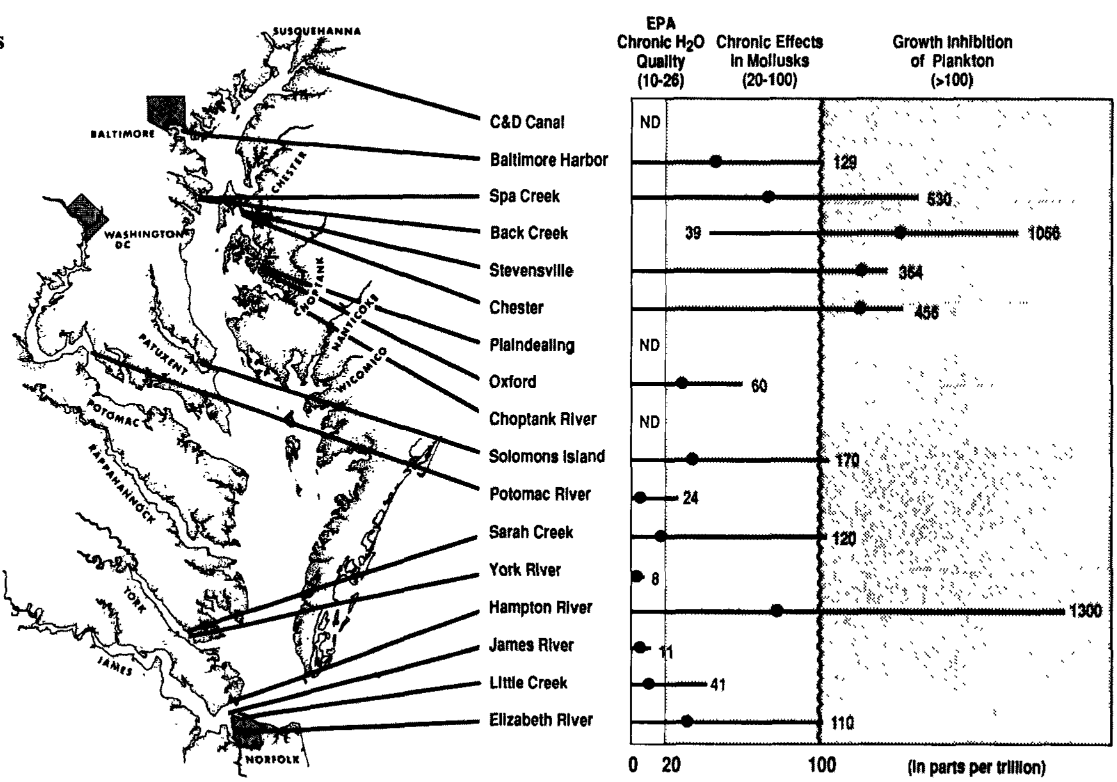
Data from other Virginia sites also correlated with boating and shipping activity. The range and average of TBT concentrations for the Hampton and Elizabeth rivers indicate greater local TBT sources compared to the York and James sites where TBT concentrations averaged less than 10 pptr.

Resultant Management Actions

Based on the findings from the TBT monitoring programs, research findings on TBT toxicity to estuarine organisms and EPA's special review, Maryland and Virginia passed legislation to restrict the use of TBT-based antifouling boat paints. The TBT Workgroup cooperated with the Chesapeake Bay Commission to ensure approval of this legislation. Passage of the Maryland and Virginia laws provided a model for resultant legislation passed by numerous coastal states and for national legislation enacted in 1988.

Data from ongoing monitoring in Chesapeake Bay were submitted to EPA's Office of Pesticide Programs,

Figure 1. The map shows all sampling sites in Chesapeake Bay where scientists have measured TBT in the water since 1984. The lines show the range of values measured over the sampling period while each dot represents the average TBT concentration found at that site. At the majority of sites, TBT levels exceeded the EPA water quality criterion. Several stations showed levels sufficiently high to cause abnormalities in some organisms.



ND=Non Detectable

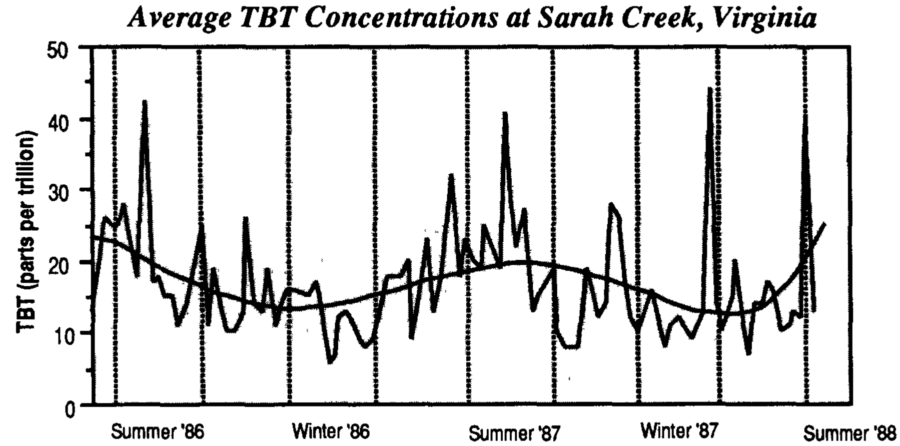


Figure 2. TBT concentrations at Sarah Creek, tributary to the York River, show peaks which coincide with the late spring and summer boating season. TBT levels drop off during the winter when most recreational boats are out of the water.

which had responsibility for the special review of TBT. This data set, the most complete and extensive for such a large coastal system, has played a significant role in EPA's risk/benefit analysis of TBT. EPA has since published regulations cancelling or restricting the use of TBT antifouling paints based in part on the Chesapeake Bay TBT monitoring data and research findings.

Effectiveness of Legislation and Regulations

Congress has requested that EPA carry out a ten-year national TBT monitoring program to assess the effectiveness of the national legislation in reducing environmental levels of TBT. Member agencies of the Chesapeake Bay Program will continue to coordinate TBT monitoring programs in a regional effort to evaluate national and state actions to diminish contamination of the Bay by TBT.

Kepone in the James

The James River, the southernmost tributary of the Chesapeake, is the third largest tributary entering the Bay. It supplies about 16% of the freshwater flowing into the Chesapeake. The river originates in West Virginia and drains approximately one quarter of Virginia. It boasts a diverse and valuable fishery with much of the river forming important spawning and nursery grounds. Major shellfish species harvested in the James River include hard clams, blue crabs and oysters. Seed oysters, juveniles of 1-6 cm in length, are abundantly harvested from the James and sold to watermen for planting in oyster-depleted areas of the Bay. Scientists estimate that 70% of the annual Virginia oyster production is dependent on seed oyster production in the James.

Kepone Contamination

From 1966 through 1975, Allied Chemical Company and its subsidiary Life Science Products, Inc (LSP), produced a persistent chlorinated hydrocarbon insecticide called kepone. During production, the company discharged kepone into the James River Estuary at Hopewell, Virginia. They released an estimated 90,720 kg of kepone to the environment through atmospheric emissions, wastewater discharge and disposal of off-specification batches. Kepone contaminated the river from Hopewell to Newport News; scientists found fish adulterated with the substance as far upriver as Richmond.

In July 1975, the Virginia Department of Health (VDH) closed Life Science Products due to inadequate employee protection in kepone production. State and federal governments formed task forces to evaluate the situation and recommend action. Due to an overall lack of knowledge concerning kepone, they also initiated research efforts.

The EPA modeled the movement of kepone in the estuary, investigated means of kepone disposal and fixation and determined the potential effects of kepone on marine organisms. At the same time, VIMS evaluated the impact of kepone on aquatic animals, its accumulation in sediments and biota and the uptake and release of the toxicant by specific animals. The VDH simultaneously researched the human health aspects of the kepone problem.

State and federal agencies initiated environmental monitoring to determine the extent and degree of the kepone problem. They found widespread contamination of the water, sediment, fish, and shellfish. As an extension of the initial study, the Virginia State Water Control Board designed and implemented a long-term monitoring program to evaluate and track the kepone problem.

Monitoring Kepone

In the Water. Scientists collected and analyzed James River water samples from approximately 60 stations for kepone from 1976 through 1981. Levels in the water were highest in the middle reach of the estuary from Jordan Point to Jamestown Island and decreased towards the sea. Concentrations peaked in the summer. Water sampling was finally eliminated from the monitoring program in 1982 due to continuous non-detectable and trace levels of kepone.

In the Sediment. As part of the ongoing monitoring program, scientists collect core sediment samples throughout the river and analyze for kepone at different depths below the sediment surface. Sediment monitoring stations are located throughout the entire contaminated reach of the river. From 1976 through 1981, technicians collected samples at approximately 60 stations. Stations where kepone was not detected have been dropped over the years. From 1982 through the present, 32 stations have been sampled annually.

Kepone accumulates in the sediment due to its affinity for particulate material. It associates with coarse sediments having high organic content in the upper and middle river. In the lower river, it generally associates with fine-grained sediments. Higher sedimentation rates in the channel tend to bury the contaminated sediment while lower rates in shoal areas allow contaminated sediment to remain at the surface.

Kepone levels in sediment also vary greatly along the river. The Hopewell area shows high levels of contamination but this drops below detection downriver at Newport News. Kepone contamination is greatest where fresh and salt water meet; the mixing of seaward-moving fresh water and salt water moving upriver traps much of the contaminated river-borne sediment load. Kepone levels in James River sediments have generally decreased since the onset of the monitoring program as a result of the burial and dilution of kepone-containing sediments by less contaminated sediments.

In the Finfish. A large data base and knowledge of the kepone situation has allowed the fish monitoring program to be reduced over the years while still providing the necessary portrait of kepone levels in James River fish. Currently, nine target species are

Kepone, a complex insecticide, is known to chemists by the bewildering name of decachloro-octahydro-1,3,4-meheno-2H-cyclobuta[cd]=penatalen-2-one. Chemically, it is similar to chlordane, mirex, aldrin, and dieldrin. In the past, the majority of kepone was shipped abroad to eradicate the Colorado potato beetle in Europe and the banana borer in Central America. Its use in the U.S. was limited to ant and roach traps.

Kepone is highly persistent in the environment and becomes increasingly concentrated as it moves through the food web. Humans exposed to sufficient quantities of this toxicant may sustain serious medical complications, including tremors, reproductive problems, and liver damage.

Until 1975, there were 26 companies in the U.S. producing 53 kepone-containing products. Although EPA issued a stop sale order in August 1975, it wasn't until May 1978 that EPA banned further use of kepone in any product.

monitored in the tidal reach of the river from Richmond to Newport News. Since the onset of the monitoring program, overall kepone levels in fish have decreased although there have been annual fluctuations.

Fish accumulate kepone relative to their length of exposure to the pesticide. Species-specific characteristics such as feeding preferences, location of spawning and nursery areas, migratory patterns and metabolism also influence the uptake, breakdown and elimination of kepone. No correlation between the size or sex of the fish to kepone levels has been consistently found. Kepone does have an affinity for lipids, so tissues with a higher fat content incorporate more kepone. The brain or liver of a fish, for example, generally contains higher levels of kepone than the edible meat of the fish.

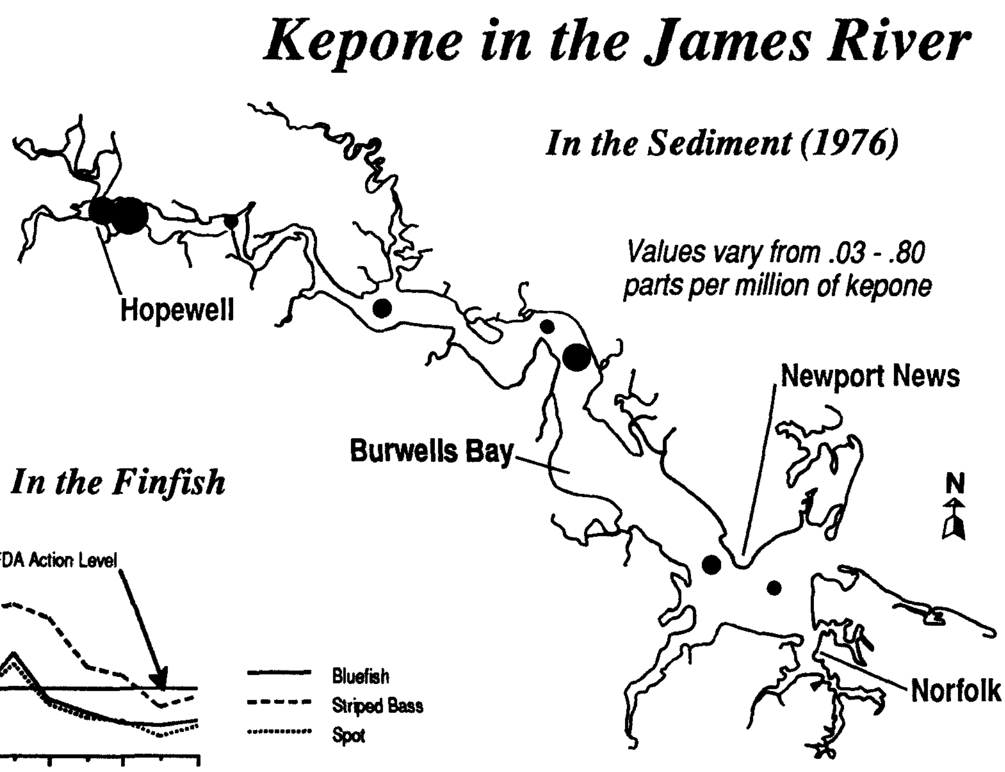
Seasonal differences in kepone levels in fish are evident in migratory fish. Resident fish, such as largemouth bass and sunfish display no seasonal kepone variation since they remain in the James River all year. On the other hand, migratory fish species enter the river in the spring, acquire kepone through the food web and migrate out of the river in the fall. As long as the fish inhabit the river, they are exposed to kepone. This exposure causes levels in the spot, croaker, trout and bluefish to rise the longer the fish remain in the river.

Kepone levels are greatest in fish collected from Hopewell to Burwells Bay (Figure 3). Since sediment kepone levels are higher in this area, more of the substance is available to fish for uptake. In other Bay areas, such as the York and Rappahannock rivers, Chickahominy Lake and Chesapeake Bay, kepone is generally not detectable in the fish.

The Current Status

With the discovery of widespread kepone contamination of water, sediment, finfish, and shellfish in 1975, the state closed the James River to all finfish and shellfish harvesting. After a thorough review of the initial data, the state permitted catches of shad, herring, catfish and female blue crabs. The fishing ban has been further modified over the years as scientists gathered additional monitoring information. In 1980, the sportfishing ban was lifted. By 1981, commercial fishing resumed for shellfish and all finfish except striped bass. As the information base expanded, the state again placed restrictions on certain fish species. By 1984, it opened the river to spot fishing and the restrictions were allowed to expire in 1988 when kepone levels in all fish remained consistently below the FDA action level.

The water, sediment and finfish of the James River are still contaminated with kepone and scientists do not predict complete cleansing of the river. Fortunately, kepone levels in all areas have decreased and should slowly continue to drop over the years. Now, the extensive and valuable fishery of the James River can once again realize its full potential. Meanwhile, monitoring of kepone levels in the sediment and fish will continue throughout the contaminated reach of the James River, providing the necessary assurance that consumers of Virginia's seafood industry remain protected.



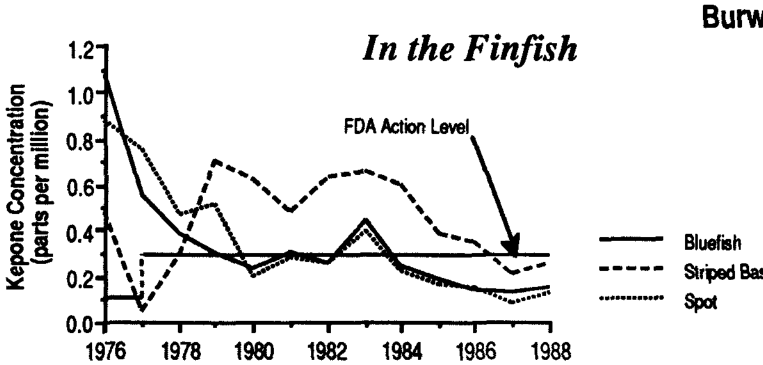


Figure 3: In 1976, after LSP stopped producing kepone, the sediments in the James were still heavily laden with the toxic substance (dot size corresponds with concentration). Eleven years later, levels of kepone at the same stations were non-detectable. The finfish show elevated kepone levels in their tissues throughout the 1970s. While dropping below the FDA action level in bluefish and spot after 1980, the substance persisted in the striped bass.

Towards the Future

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Monitoring key indicators that define the Bay's health, as well as the major pollution sources we are attempting to control, will continue to play a crucial role in marking our progress and refining our plans well into the next century. The next milestone for use of the monitoring information will come in 1991 when Bay managers and scientists will reevaluate the current baywide nutrient reduction strategy.

1991 Reevaluation

Top government officials in the Bay region made a bold decision in 1987 when they committed to a 40% reduction of nutrients entering the Bay by the year 2000. While this step was clearly needed in the Bay's restoration, they also recognized that more definitive information on the status of the Bay, its response to past management actions and projections of its response to new initiatives would soon be available. The signatories to the 1987 Bay Agreement, therefore, agreed to reevaluate the nutrient reduction strategy in 1991.

Findings from the analysis and interpretation of Chesapeake Bay Monitoring Program data will be a cornerstone in the reevaluation process. Monitoring information will provide quantitative profiles of both water quality and living resources for each of the Bay's major basins. By coupling this information with the monitoring of nutrient loadings and the most current thinking on water quality goals, managers will develop a set of nutrient reduction strategies for each basin. These strategies can then be tested in the 3-dimensional mathematical model of the Bay which would not have been possible without the comprehensive water quality monitoring program.

The Chesapeake Bay Monitoring Program will have three critical functions in the 1991 Baywide Nutrient Reduction Strategy reevaluation:

- Provide Bay managers and the public with insights on past trends (1950s-1980s) and the current status of water quality, habitat quality and living resources through analysis of the comprehensive Chesapeake Bay database for the tributaries and mainstem Bay;
- Provide measures of the "environmental effectiveness" of the nutrient reduction approaches implemented since 1984 through analysis of nutrient loadings, ambient water quality and the abundance and diversity of living resources.
- Provide the data needed to develop and calibrate the time-variable water quality model of the Bay and to assist in formulating the nutrient reduction scenarios which will be tested with the model.

Developing Issues

An information baseline is now firmly established with the recently instituted programs and trends are emerging. While maintaining the current monitoring programs to provide the consistent information that long-term management requires, we also need to be responsive to emerging issues demanding our immediate attention. Some of the topics which will likely be the focus of additional monitoring and research follow.

Atmospheric Loadings

Worldwide, scientists have become increasingly concerned over atmospheric deposition in the past several years as they continue to document the far-ranging effects of acid rain and aerial deposition of toxicants and nitrogen. The Chesapeake has not escaped this form of pollution and scientists are now evaluating the significance of these "nonpoint source" nutrients and toxicants. Research on the environmental impacts of acid precipitation has led to questions concerning the contribution of atmospheric deposition to the nutrient budgets of lakes and estuaries. With the discovery of pesticides and other toxicants in lakes on uninhabited islands in the Great Lakes and other evidence of aerial transport of toxicants, the need to explore further this process of contamination is clear.

Findings from the limited atmospheric deposition monitoring within the Bay basin demonstrate the need for further quantification of atmospheric sources of nutrients and toxicants. Future coordinated monitoring will focus on:

- Quantification of atmospheric contributions to nutrient and toxicant budgets of the Bay and its tributaries; and,
- Implementation of programs to document the extent of stream acidification in the Chesapeake Bay watershed.

Toxicants

With implementation of the basin-wide Toxics Reduction Strategy, monitoring will play an increasingly important role in targeting actions to reduce the effect of toxicants on the Bay. Existing monitoring programs analyze sediment and tissue contaminant levels over wide geographic areas, identifying "hot spots" on a baywide scale. Under the Bay strategy, there will be additional coordination and targeting of toxicant monitoring programs.

Chesapeake Bay monitoring of toxicants in the 1990s will be used to:

- Determine the regions and compounds of concern leading to the design of more site and toxicant-specific monitoring programs;
- Pinpoint the origin and quantify the contribution of toxicants entering the Bay and its watershed, including point (municipal, industrial, urban stormwater) and nonpoint (agricultural, atmospheric, shipping, urban runoff) sources; and,

- Locate areas of ambient toxicity in critical living resource habitats and identify potential sources of the toxicants using mobile bioassay laboratories and field sampling.

Baywide Fisheries Management

The 1987 Bay Agreement called for baywide fisheries management plans that would foster unprecedented cooperation among the various jurisdictions charged with fisheries management responsibility. Several of these plans have already been adopted and they point to the need for better monitoring information—both for fish populations and their habitats.

With existing habitat and living resource monitoring data, scientists are now making the links between habitat integrity and the distribution and abundance of plant and animal species. Each species requires a distinct set of habitat requirements—man can control some factors although natural processes play exceedingly important roles. Through a better understanding of habitat requirements and current conditions we will be able to set water quality goals that are more responsive to the needs of the Bay's living resources.

Conclusion

Through concerted efforts to utilize the best available monitoring information, maintain long-term continuity and be responsive to new issues, the monitoring programs can provide the guidance for the restoration and protection of the Bay's resources. Our recent efforts to work cooperatively throughout the region in solving the Bay's problems have attracted attention as a model for other regions in the nation and other countries. As recent evidence of atmospheric pollution indicates, we also need to be cognizant of events occurring outside the 64,000 square mile drainage basin of the Chesapeake Bay.

Ultimately, the goal of the Chesapeake Bay Program is to restore the Bay's plants and animals to healthy and balanced levels. Management of these living resources, stressed from fishing pressure and declining habitat quality, must continue to be supported by sound, baywide monitoring data. With a firmly established link between findings from the monitoring programs and refined management of the Bay basin, we can be more confident than ever in our prospects for success in restoring and protecting the bounties of the Chesapeake.