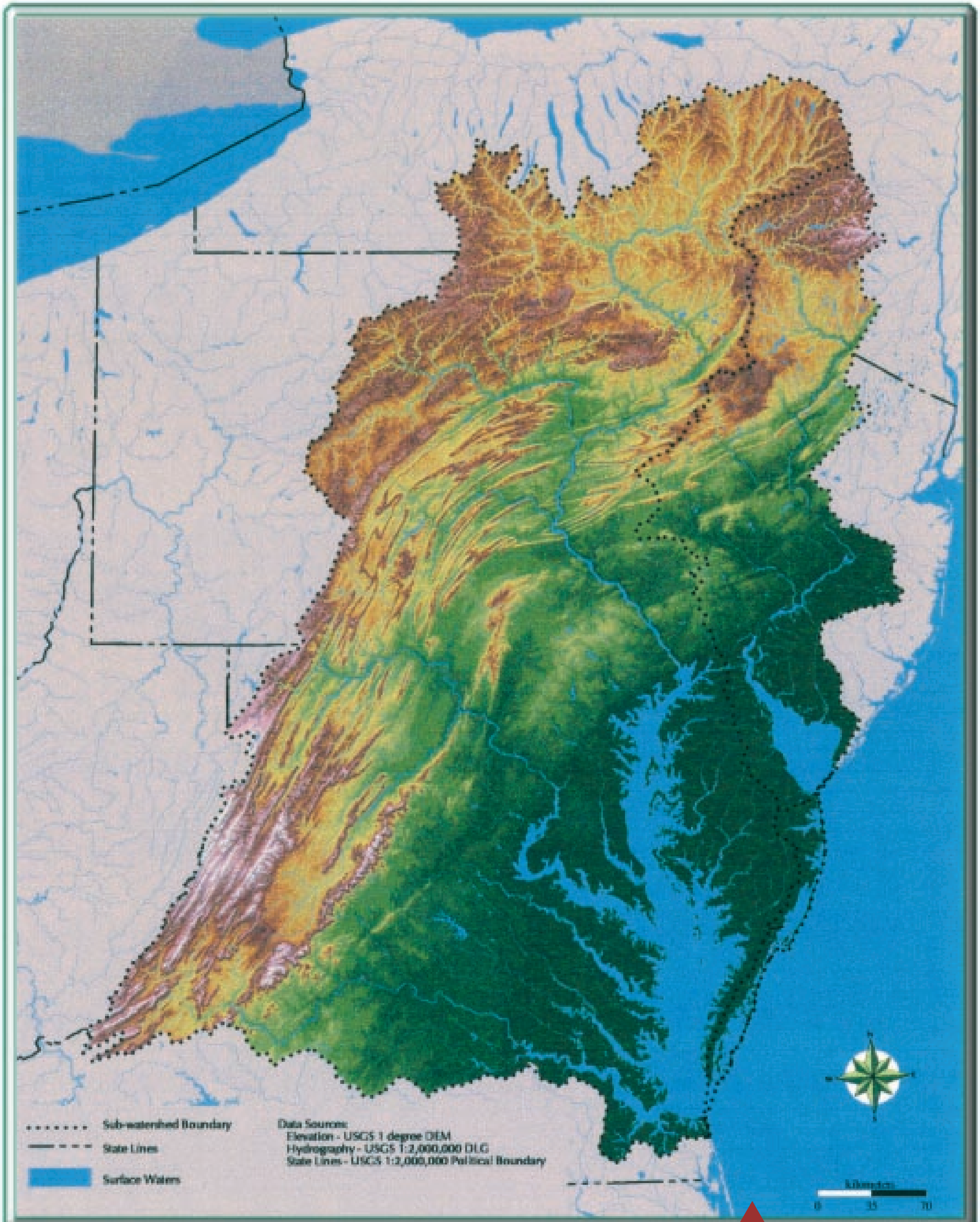
United States
Environmental Protection
Agency

Office of Research and
Development
Washington, DC 20460

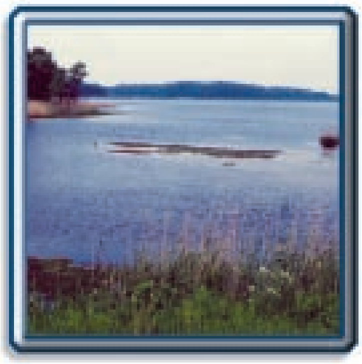
EPA 600-R-98-147
November 1998
www.epa.gov

EPA

Condition of the Mid-Atlantic Estuaries



Watershed of the Mid-Atlantic estuaries



Greetings from the U.S. Environmental Protection Agency

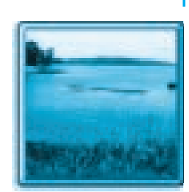
Chesapeake Bay, Delaware Estuary, and Delmarva coastal estuaries are vital Mid-Atlantic resources. They provide habitat for many kinds of animals and plants, including commercially valuable fish and shellfish, and are enjoyed each year by millions of recreational boaters, fishermen, and other visitors. For many years, the U.S. Environmental Protection Agency (EPA) has led efforts to protect and restore these estuaries by implementing such laws as the Clean Water Act and by participating in projects like the Chesapeake Bay Program.

Are these protective measures having an impact? What is the current condition of our natural resources? How widespread are ecological problems and what are their probable causes? To answer these questions, and to identify the most effective protection measures for the future, we need to regularly take stock of our natural resources. EPA is now pursuing these goals by preparing a series of State-of-the-Region Reports for the Mid-Atlantic, of which this report is the first. These peer-reviewed reports aim to gather and evaluate the best available scientific information and knowledge about the ecological resources of the region. Future reports will address the condition of our streams, forests, and other resources.

This report breaks new ground in employing the latest scientific tools and by drawing upon carefully designed sampling plans that provide broad coverage of all of these estuaries. It also demonstrates the value of forging close scientific collaboration among federal and state agencies and other organizations. We hope this report will help you understand more about the estuaries and encourage further efforts to protect these natural treasures.

W. Michael McCabe
Regional Administrator
Region III

Henry L. Longest II
Acting Assistant Administrator
Office of Research and Development



Acknowledgements

This report, *Condition of the Mid-Atlantic Estuaries*, was prepared by staff from the Atlantic Ecology Division (AED), National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Narragansett, Rhode Island. The staff included John F. Paul, Technical Leader, Brian Melzian, Technical Coordinator, Barbara S. Brown, Branch Chief, and team members Charles Strobel, John Kiddon, James Latimer, Daniel Campbell, and Donald Cobb. The report was prepared with the collaboration of individuals from Delaware Department of Natural Resources and Environmental Control, Maryland Department of Natural Resources, Virginia Department of Environmental Quality, National Oceanic and Atmospheric Administration, U.S. Geological Survey, U.S. Fish and Wildlife Service, EPA Regions II and III, AED Community-Based Assessment Team in Annapolis (special thanks to Tom DeMoss, Pat Gant and Ron Landy), Kevin Summers and others from EPA/ORD Gulf Ecology Division, EPA/ORD Western Ecology Division, Chesapeake Research Consortium, and EPA Office of Policy, Planning, and Evaluation. Geographic information systems support was provided by Jane Copeland, Randy Comeleo, and George Morrison, OAO Corporation. We would like to thank William Nelson, Gerald Pesch, Richard Pruell, Steven Schimmel, Darryl Keith, and Walter Galloway of EPA/AED; Robert Diaz; and Kenneth Tenore; as well as a large number of other reviewers from government and academia for their valuable reviews of this document. This report represents the synthesis of information published in a variety of scientific reports or contained in established scientific databases. We collected no new data specifically for the production of this report. We thank the many researchers involved in the original collection and reporting of these data.

Because of the vast number of different research projects producing the data used in this report, no attempt was made to verify the quality of these data. It was assumed that if the data were published or were stored in established databases that they had been verified. However, any data that appeared "unusual" or questionable were checked with the originator of those data. The spatial displays presented in this report were not prepared to meet EPA spatial locational guidelines; the displays were prepared from disparate datasets and represent a best attempt at approximating locations.

This report has been reviewed and approved for publication by the U.S. Environmental Protection Agency. Approval does not signify that the contents necessarily reflect the views and/or policies of the EPA. Mention of trade names, products, or services does not convey, and should not be interpreted as conveying, official EPA approval, endorsement, or recommendation.

This report is contribution USEPA-NHEERL-NAR-1822 of the Atlantic Ecology Division of the EPA National Health and Environmental Effects Research Laboratory.

Executive Summary

Estuaries are transitional zones where salt water from the sea mixes with fresh water flowing off the land. Estuaries in the Mid-Atlantic Region provide habitats for many birds, mammals, fish, and other aquatic life. They also are important assets that humans use in a wide variety of ways. This report focuses on the current condition of the Mid-Atlantic estuaries (circa early to mid 1990s) and, where information is available, how the estuaries have changed over the years and why.

The pervasive issues across the **Mid-Atlantic Region** include the oyster harvest and disease in shellfish. Shellfish, particularly the American oyster, traditionally have been one of the major living resources harvested in the Mid-Atlantic states. Oyster harvests have declined from a high of 133 million pounds in 1880 to today's annual catch of about one million pounds. Disease, specifically Dermo and MSX, appears to be one of the major causes of the recent drastic decline in oyster populations in Chesapeake Bay and the Delaware Estuary, with over-harvesting and pollution also playing a major role in Chesapeake Bay. Although no immediate solution to the problem is known, researchers currently are working on the concept of introducing disease-resistant strains of oysters to the Mid-Atlantic. With the decline of the oyster industry, the most important shellfish industry in the Mid-Atlantic Region is now the blue crab. However, the significantly increased fishing pressure on the already heavily exploited population is beginning to take its toll. To avoid a serious impact, both Maryland and Virginia have placed restrictions on crabbing in Chesapeake Bay waters.

The **Delaware Estuary** is characterized by an historical lack of submerged aquatic vegetation (SAV), due predominantly to naturally-occurring low water clarity. It is also one of the most nutrient enriched estuaries in the world, although harmful phytoplankton blooms are held in check by other factors, including low water clarity. The estuary also is highly impacted by lingering toxic contaminants associated with urbanization and industrialization of the Delaware River. The Delaware Estuary has some of the nation's highest levels of chemical contaminants in fish and shellfish. Fishing bans or advisories on the consumption of finfish are posted for parts of the estuary because of elevated PCB concentrations. Concentrations of Chlordane in fish exceeding the FDA action level have been reported in the upper estuary.

Photo by: U.S. Fish and Wildlife Service

Chesapeake Bay continues to be affected by low dissolved oxygen and is the most hypoxic estuary in the region. Low dissolved oxygen levels are associated with

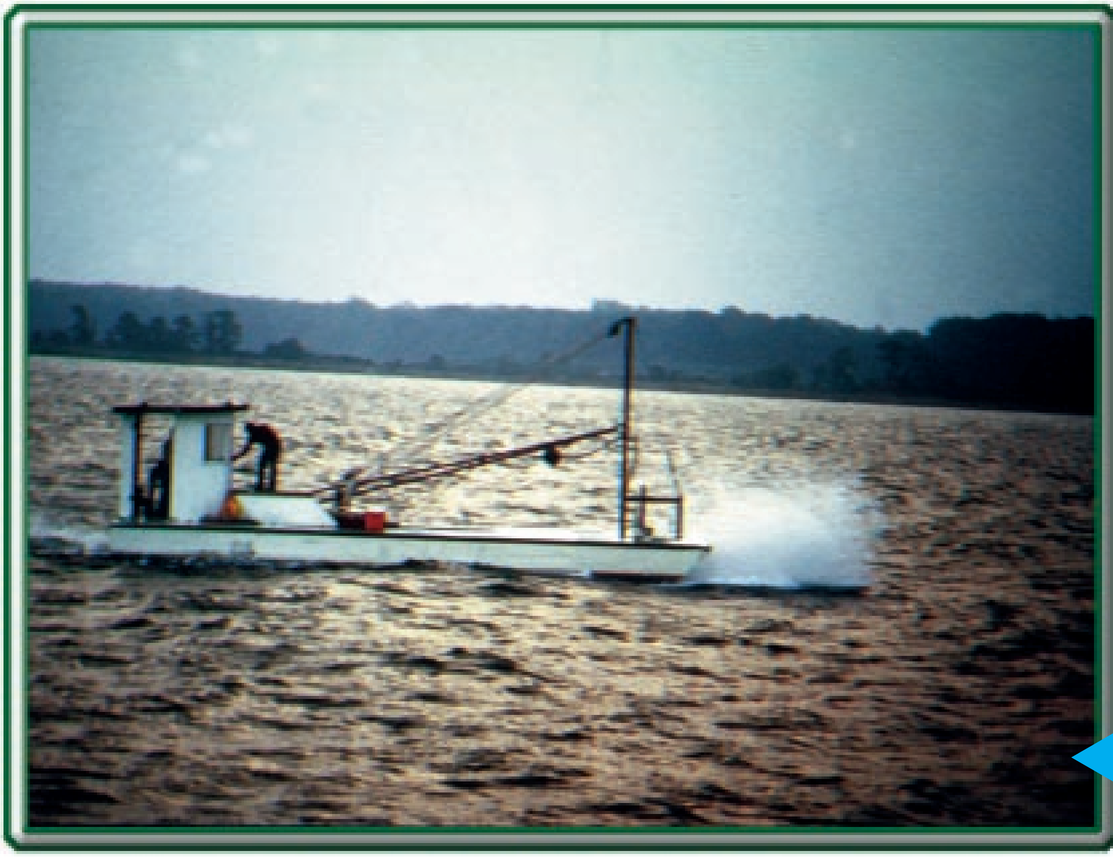


Photo by: U.S. Fish and Wildlife Service

nutrient overenrichment and eutrophication. In 1987, the Chesapeake Bay Agreement stipulated a 40% reduction in nutrient loading by the year 2000. Nutrient levels in Chesapeake Bay are declining in response to improved wastewater management practices, implementation of best management practices on agricultural lands (nitrogen), and bans on certain types of detergents (phosphorus). However, there has been more success in controlling point sources than nonpoint sources of nutrients. Historically, high nutrient concentrations have contributed to prolonged phytoplankton blooms in the Bay. Blooms during the 1970s and 1980s significantly reduced water clarity and, as a result, contributed to the massive loss of SAV that occurred during that time period. This critical habitat has since partially recovered.

The **Delmarva coastal bays** are the least degraded systems in the Mid-Atlantic Region but are threatened by encroaching urbanization. These bays are moderately enriched, particularly in Delaware, largely from agricultural sources. Eutrophication is increasingly noticeable in the dead-end canals along developed shorelines in the Delmarva coastal bays. SAV historically has been absent from the Delaware portion of the coastal bays because of high natural turbidity in these systems. Species composition of shore zone fish in the Delaware coastal bays indicates impacted environmental conditions. In contrast, Maryland coastal bays' species composition suggests a healthy habitat; however, researchers have observed evidence of early stages of degradation in northern areas.

Coastal waters presently exhibit low levels of nutrients and chlorophyll. However, evidence suggests that these levels may be rising, indicating the potential for future environmental problems.

Estuaries of the Mid-Atlantic Region are being adversely affected by man's activities. Therefore they need active management if environmental quality is to be sustained. The states, in conjunction with EPA through the Chesapeake Bay Program and the National Estuary Programs, have instituted successful environmental management programs to address these environmental challenges.

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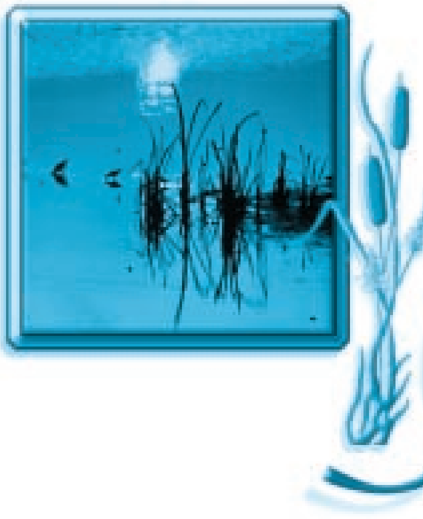
Contents

Developmental pressures have resulted in substantial habitat change in the Mid-Atlantic. Coastal Wetlands have been destroyed for residential and commercial development. The submerged aquatic vegetation, which provides food, shelter and nursery grounds for many species of shellfish, finfish, and other organisms, has decreased as human population has increased.

Fish and other aquatic life are often the first affected by the substances deposited in our waterways. Since they are also consumed by people, the condition of our living resources is a significant public health concern.



Introduction

A broad-scale view of the ***Mid-Atlantic Region***[1] of our country reveals that local ecological resources such as water supplies and wildlife do not exist as isolated groups but are interconnected across long distances. The health of blue crabs in Virginia or waterfowl in Delaware can be affected by conditions dozens or even hundreds of miles away. Therefore, studying and protecting ecological resources must take a similarly broad view. EPA is working to implement just such an approach through its Office of Research and Development and the Region III Office, which is based in Philadelphia and encompasses the District of Columbia and the states of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia.

Photo by: Chesapeake Bay Program

In this report, the first in a series of State of the Region reports, we present information on ***estuaries*** in EPA Region III, which includes Chesapeake Bay, the Delaware Estuary, and the coastal bays on the Atlantic coast in the states of Delaware, Maryland, and Virginia ***(Delmarva Peninsula).***

To properly assess the ecological condition of Region III's estuaries, one must look at more than just the water bodies themselves. The entire ***watershed*** must be studied, meaning all the land that drains into these estuaries. For this reason, this report uses information extending beyond the political bounds of EPA "regions," treating the estuaries as ecological units rather than political entities.

Information in this report will be presented primarily as *percent* of the estuarine area in some desired or undesired condition, rather than the actual area (square miles). This will allow easier comparison between subregions. For example, questions like "Is more of Chesapeake Bay in an undesired condition than the Delaware Estuary?" will be addressed. If area estimates were compared, Chesapeake Bay would dominate almost all comparisons because of its size (81% of the estuarine surface area in the region). The actual areas can be compared by multiplying percent area by the areas given in the next chapter.

What are estuaries?

Estuaries are transitional zones where salt water from the sea mixes with fresh water flowing off the land. For this report we will use the term estuaries to include waters that extend from the coast of the Atlantic Ocean (or boundaries that extend across the mouths of the Delaware Estuary and Chesapeake Bay) upstream to the fresh waters that drain to the ocean as far as the influence of the tide is detectable. For rivers like the Susquehanna, this tidal influence is limited to the first dam encountered as one goes upstream. For others, such as the Delaware and Potomac Rivers, the tidal influence can extend many miles upstream to the ***fall line.*** The ***salinity*** of estuaries can range from full strength sea water to ***brackish*** to fresh water. When we discuss the condition of estuaries, we mean the condition of the waters that span this full range of salinities.

[1]**Terms in the glossary are *highlighted* at first usage.**

Why are estuaries important?

Estuaries are valuable in many ways. They provide important habitat for thousands of ***species*** of plants and animals. As ***spawning***, nursery, and feeding grounds, they are invaluable to fish and ***shellfish***. These waters provide corridors for ***anadromous fish*** that migrate upstream to spawn.

Estuaries support many kinds of natural ***habitats***, including ***wetlands***. Wetland habitats are used by shorebirds, migratory waterfowl, fish, ***invertebrates***, reptiles, and mammals. They are the home to many ***threatened*** or ***endangered*** species. Wetlands also improve water quality by filtering out pollutants and ***sediment***, and serve as buffers that protect upland areas from flooding. They also stabilize shorelines and stream banks from erosion.

In addition to their biological and habitat value, estuaries provide for many diverse human uses. They supply water for municipalities, industry, and agriculture; support commercial and sport fisheries; and support tourism and recreation. They also are important locations for manufacturing and shipping. Finally, estuaries are valued for their aesthetic qualities.

How are estuaries threatened?

Estuaries are threatened because of the numerous ways that humans use them and the land area that drains into them. As a result, they exhibit a multitude of environmental problems. The most common problems—degraded natural habitats, declining plant and animal populations, diminishing fish and shellfish harvests, and impaired water quality—are clearly observable in parts of the estuaries in the Mid-Atlantic Region. Growth of human populations in the estuarine watersheds, combined with the spread of industrial and agricultural technologies that are potentially harmful to ecological systems and place greater demands on natural resources, has adversely affected our valuable estuarine ecological systems. Most of the problems observed in estuaries are related to ***land use*** practices and are closely linked to human population density. The northeast corridor extending from Washington to Boston, of which the Mid-Atlantic is part, is one of the most densely populated areas of our country.

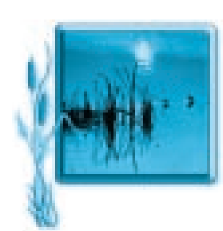
What dynamics occur in estuaries?

This report is an accounting of our estuarine resources at the present, which are, in part, the legacy of our past actions. Our description of these resources is a snapshot of estuarine conditions in the Mid-Atlantic Region based upon currently available information. However, we know that ecological systems adapt and evolve with time under the influence of external factors, that also change

Estuaries are home to a wide variety of wildlife.
Photo by: U.S. Fish and Wildlife Service

through time. This dynamic aspect of ecological systems is not the subject of this report. Nevertheless, it is the context within which this report is presented, and the present ecological conditions are the basis upon which management decisions about the future will be made.

Estuaries in the Mid-Atlantic Region are expansive and dynamic systems, consisting of physical and chemical environments, and living creatures. The fresher and saltier waters in estuaries are constantly intermingling with the rivers, ocean waters, the shoreline, and the air, all of which are changing with the tides and seasons. These natural mixing bowls of physical, chemical, and biological interactions, combined with the myriad of human uses, challenge our ability to understand and manage these great natural resources. We have attempted in this report, to summarize our current understanding of how well estuaries as a whole are doing in the Mid-Atlantic Region.



Description of the Estuarine Resource

A discussion of the characteristics of estuaries in the Mid-Atlantic Region provides a useful starting point. The estuarine waters in the Mid-Atlantic Region encompass approximately 5,467 mi^2 of surface area. These estuarine waters contain a significant amount of the estuarine area in the United States; Chesapeake Bay is the single largest estuary in North America. The estuarine areas for the major natural subregions discussed in this report are 4,431 mi^2 for Chesapeake Bay, 795 mi^2 for the Delaware Estuary, and 237 mi^2 for the Delmarva coastal bays.

What land areas do the estuaries drain?

The estuaries of the Mid-Atlantic Region drain 78,859 mi^2 of land area, with 65,712 mi^2 of these watersheds residing within the EPA Region III state boundaries. Chesapeake Bay drains a watershed of 64,325 mi^2, the Delaware Estuary drains 13,533 mi^2, and the Delmarva coastal bays drain 1,003 mi^2. About 43,710 mi^2 of western Region III in the mid-Appalachian area do not drain to the Atlantic Ocean. This land area primarily drains to the Ohio and Tennessee Rivers and Lake Erie. Runoff from these land areas does not directly affect the ***Mid-Atlantic Estuaries;*** however, transport by the atmosphere from these land areas can influence the estuarine drainage areas. Approximately 10,629 mi^2 in southern Virginia drain to the Albemarle-Pamlico estuarine system in North Carolina. This land area also does not directly affect the Mid-Atlantic estuarine waters.

How are the estuarine watersheds used?

The use of land within watersheds is a basic factor in understanding the ecological condition of the Mid-Atlantic estuaries. A pictorial representation of the ***land cover*** is shown in Figure 1. This figure displays the major land

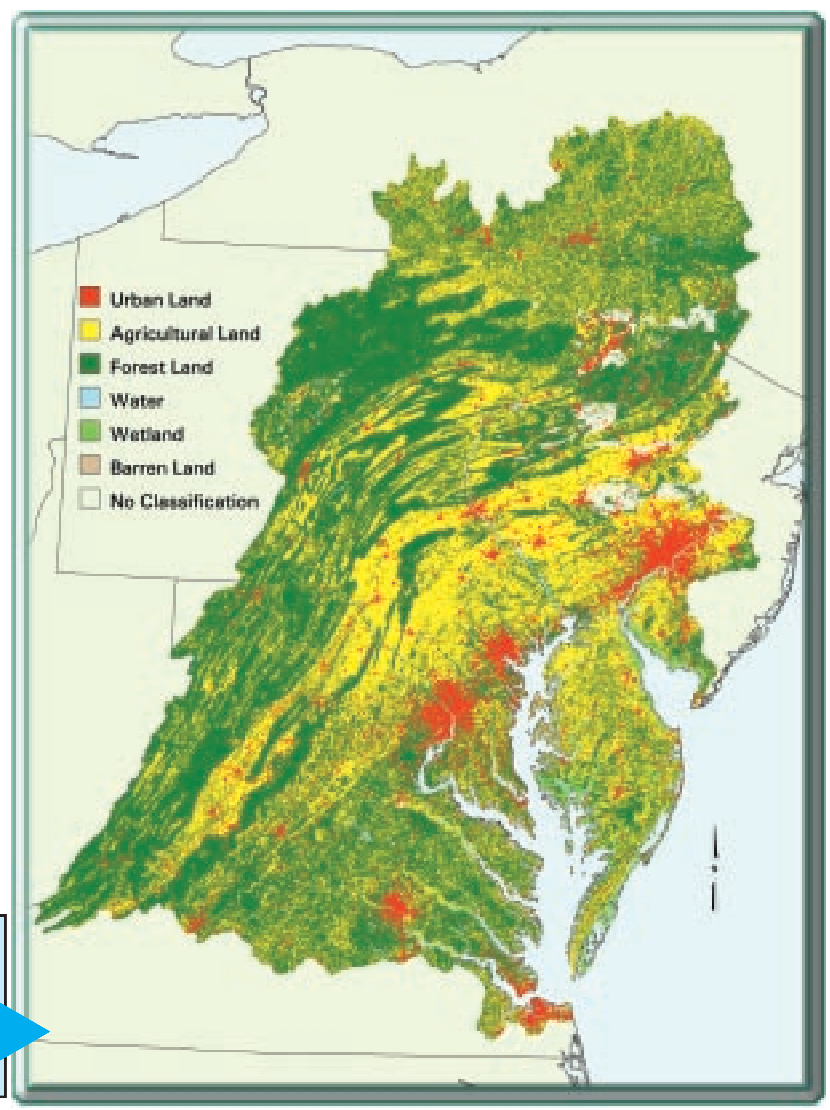


Figure 1. Land cover for estuarine watersheds in the Mid-Atlantic region.

Source: Vogelmann, 1997

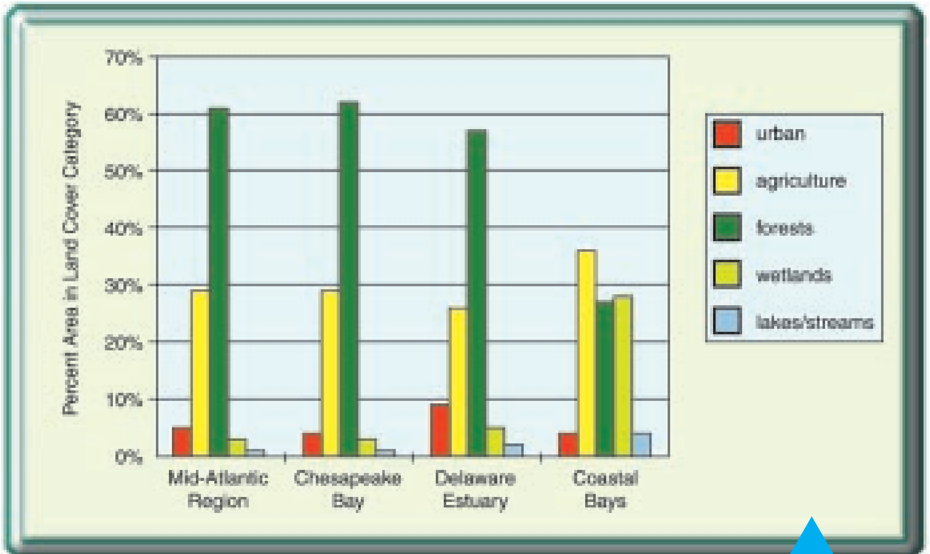


Figure 2. Land cover categories in the Mid-Atlantic Region estuarine watersheds.
Source: Vogelmann, 1997

cover categories (urban, forests, agriculture, wetlands, and lakes and streams) as classified by the U.S. Geological Survey. Figure 2 summarizes these land cover categories for the region and subregions. Note that the Delaware Estuary watershed is the most urbanized and that the land cover distribution in the Delmarva coastal bays is distinctly different from the rest of the region.

Nearly three out of every ten acres in the Mid-Atlantic watershed is currently being used for agriculture.
***Photo by*:** Chesapeake Bay Program

For the region, forest is the dominant land cover category, comprising 61% of the watershed area. Forests are important because trees filter sediment and ***nutrients*** from runoff, and their roots stabilize the shoreline and reduce erosion. They also shade the water, reducing summer water temperatures. Many of the Mid-Atlantic forests are in areas distant from estuarine shores. In some parts of the region, forests are rapidly being replaced by agricultural and urban lands.

Agricultural land comprises two groupings—pasture and cropland. Pasture land consists of grassy areas for raising and feeding livestock. Cropland is cultivated to provide various food products. Approximately one-third of the land in the region is agricultural.

Urban land (5% of the watershed) generally is close to the estuarine shoreline (see Figure 1). Urban land provides space for homes, roads, and places of employment, and increases the amount of impervious surface area (for example, pavement) and storm water runoff. As a watershed becomes more developed, the amount of pollutants carried in the storm water increases, as does the amount of wastewater and solid waste requiring disposal. The storm water flows in urban and developing areas also cause habitat damage and destruction. It is expected that the amount of urban land will continue to increase across the region.

What does the population distribution look like?

Population growth is the single most important factor underlying various impacts on Mid-Atlantic estuaries. The population has grown from 13 million residents in 1950 to 21 million in 1990 (Figure 3). By 2020 an estimated 25 million people will be living in the estuarine watershed of the Mid-Atlantic Region. Growing

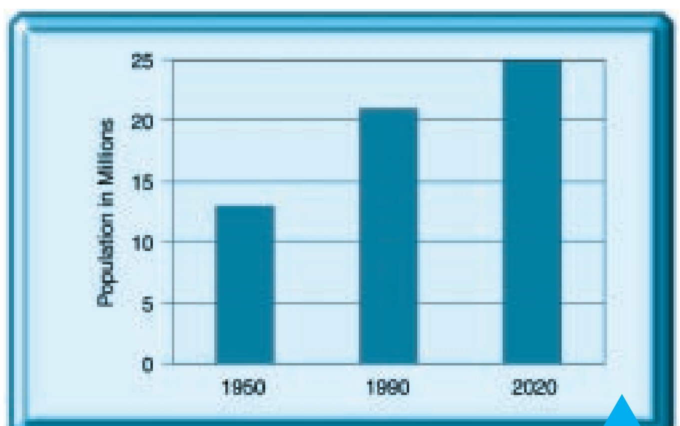


Figure 3. Human population estimates for the Mid-Atlantic estuarine watershed.
Source: Culliton *et al.*, 1990

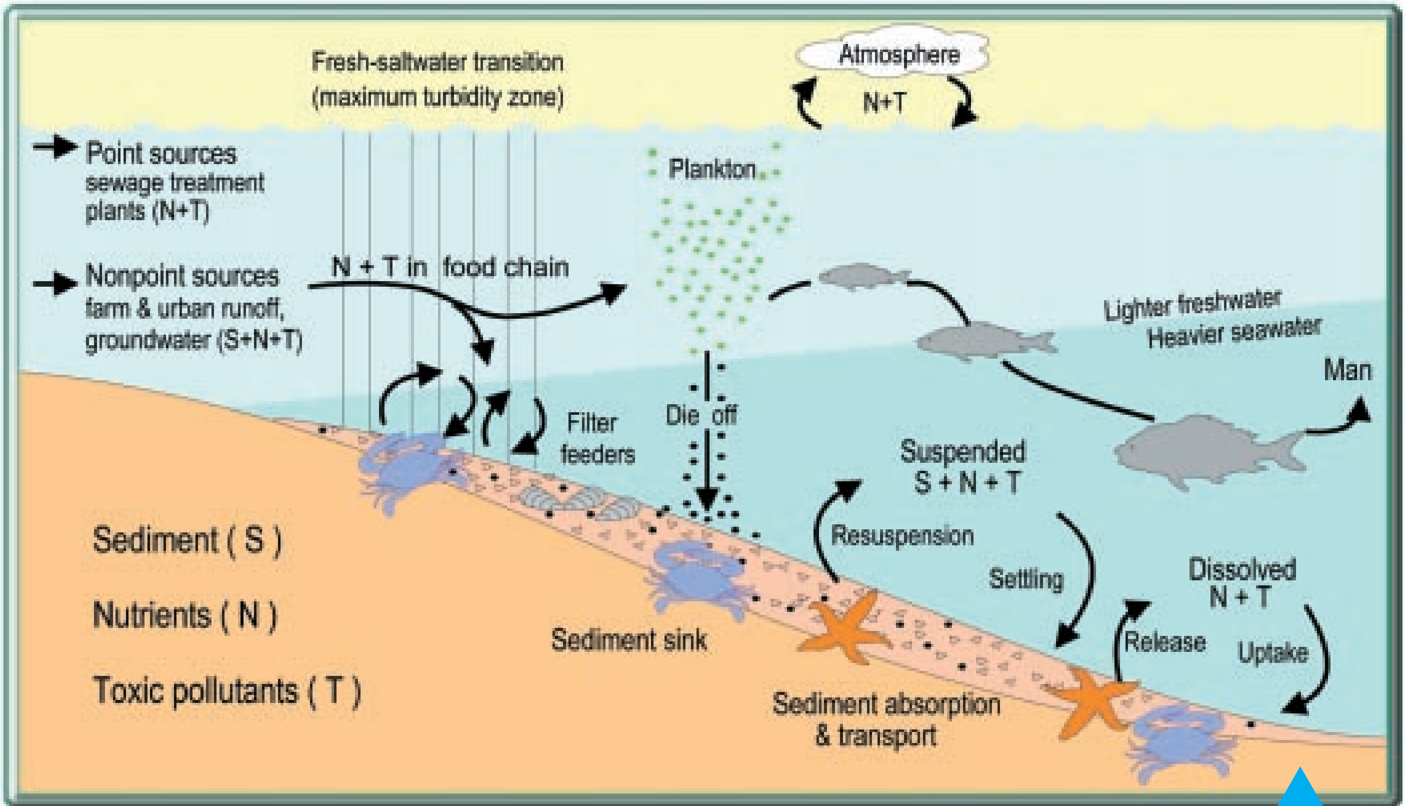


Figure 4. Schematic diagram of physical, chemical, and biological processes interacting in estuaries.
Source: Redrawn from USEPA, 1987

population requires land for homes, transportation, shops, jobs, and recreation. Forests and other land of environmental significance often are converted to meet these needs. In addition to changes in land use, population growth results in high flows from wastewater treatment plants. The volume of discharge by wastewater treatment plants has increased with the general population trend. Nevertheless, efforts to protect estuaries, such as improving wastewater treatment, maintaining buffer zones around estuaries, and controlling pollutant runoff, can offset or even reverse some of the impacts of growing populations.

What characterizes estuaries in the Mid-Atlantic Region?

A schematic description of a typical estuary is shown in Figure 4. The depth of the water is a basic parameter that influences the type of plants and animals that can inhabit the estuary. Shell fisheries usually are limited to relatively shallow areas. Plants rooted in the bottom sediments also require shallow depths. Large migratory fish typically require deeper water for their excursions. Large draft vessels are restricted to deeper portions of estuaries or to dredged channels. Water depth also influences circulation in the estuary, which in turn determines the distribution of nutrients and pollutants. Vertical ***stratification***, or layering of waters of different density, occurs in an estuary when colder, saltier water underlies warmer and fresher water. This condition can be sustained only in deeper waters because wind and tidal motions usually are sufficient to keep shallow water from stratifying. Stratification, which occurs in the mainstem of Chesapeake Bay and lower portions of the major tidal tributaries, isolates the deep layer of water from the atmosphere. As ***dissolved oxygen*** in this deep layer is depleted by decaying organic material (dead ***algae*** that sink after peak production), stratification does not permit replenishment of the dissolved oxygen from the atmosphere. This leads to the extremely low oxygen levels observed in these deeper waters. A description of dissolved oxygen conditions across the region is presented in the next chapter.

Salinity, temperature, and depth are the primary factors that affect the physical behavior of estuarine waters. Warmer, lighter freshwater flows seaward over a layer of saltier and denser water flowing in from the ocean. This stratification varies within any season depending on the rainfall and air temperature. Stratification usually intensifies in the spring as the amount of freshwater increases due to melting snow and frequent rain. Stratification is maintained through the summer due to warming of surface waters and intense rainfall. Maximum reductions of dissolved oxygen in estuarine bottom waters occur during the late summer (see section on ***"Dissolved Oxygen"***). In autumn, fresher surface waters cool faster than deeper waters and sink. Vertical mixing of the water layers occurs rapidly. This mixing moves nutrients up from the bottom sediments, making them available to ***phytoplankton*** and other organisms inhabiting the upper water levels. This turn-over also distributes much-needed dissolved oxygen to deeper waters. During the winter, water temperature and salinity are relatively constant from surface to bottom.

The degree of ***water column*** stratification is determined by the difference in density between surface and bottom water, and categorized by low, moderate, and high stratification. Summer data on stratification are depicted in Figure 5. Most estuarine waters in the Mid-Atlantic Region exhibit little or no stratification. However, deeper portions of Chesapeake Bay do become highly stratified. The Delaware Estuary has areas of moderate stratification, while Delmarva coastal bays typically are not stratified due to their shallow depths.

The average depth of estuaries in the Mid-Atlantic Region is 20 ft, with a maximum of 175 ft in the mainstem of the Chesapeake Bay. The average depth in Chesapeake Bay is 20 ft, 19 ft in the Delaware Estuary, and 5 ft in Delmarva coastal bays. The maximum depth in the Delaware Estuary is 148 ft in a shipping lane, while in Delmarva coastal bays it is approximately 115 ft at the Indian River Inlet.

Temperature dramatically changes the rate of chemical and biological activity within estuarine waters. Because

Photo by: U.S. Fish and Wildlife Service

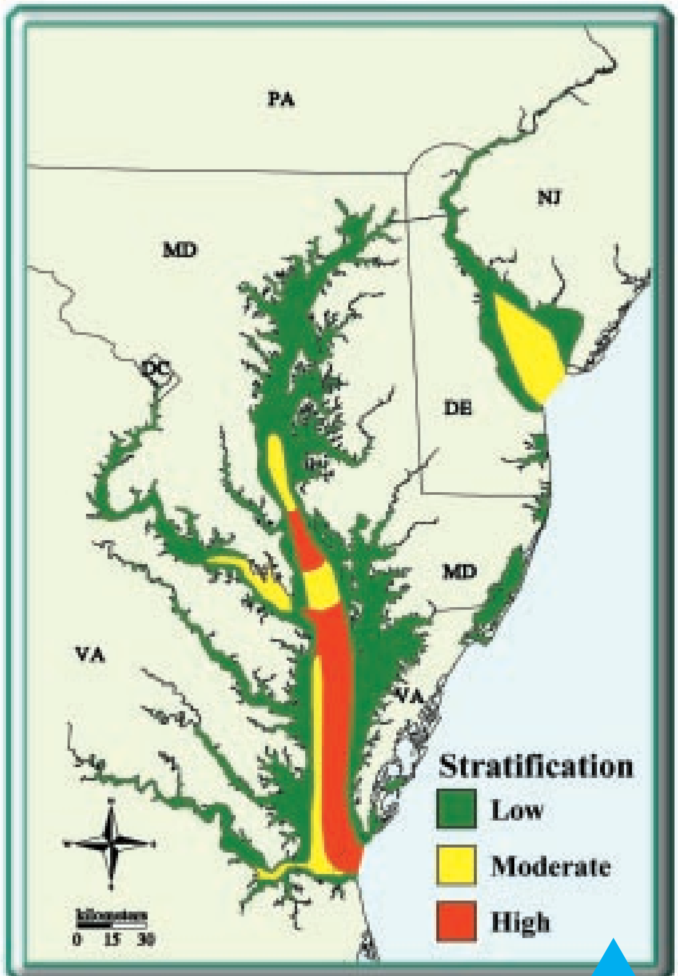


Figure 5. Summer water column stratification in Mid-Atlantic estuarine waters as observed in 1990-93. Categories are low (green), moderate (yellow), and high (red) stratification and are defined in the technical appendix.

Sources: Strobel *et al.*, 1995; Paul *et al.*, 1997

the estuaries in the Mid-Atlantic Region are relatively shallow, their capacity to store heat over the year is relatively small. As a result, water temperature fluctuates throughout the year, ranging from 32^0 to 84^0 F. These water temperature changes influence when plants and animals feed, reproduce, move locally, or migrate. The density of water is dependent on temperature, as well as salinity. In spring, as the air temperature rises, the surface waters of the estuaries warm and become stratified over the colder, heavier deeper waters. Air motion, particularly during storms, can vertically mix water. However, in deeper portions of Chesapeake Bay and the Delaware Estuary, this mixing is restricted to the upper portion of the water column.

Salinity is a measure of the total salt content in water. The common measurement unit of salinity is concentration, usually expressed as parts per thousand (***ppt***)—the

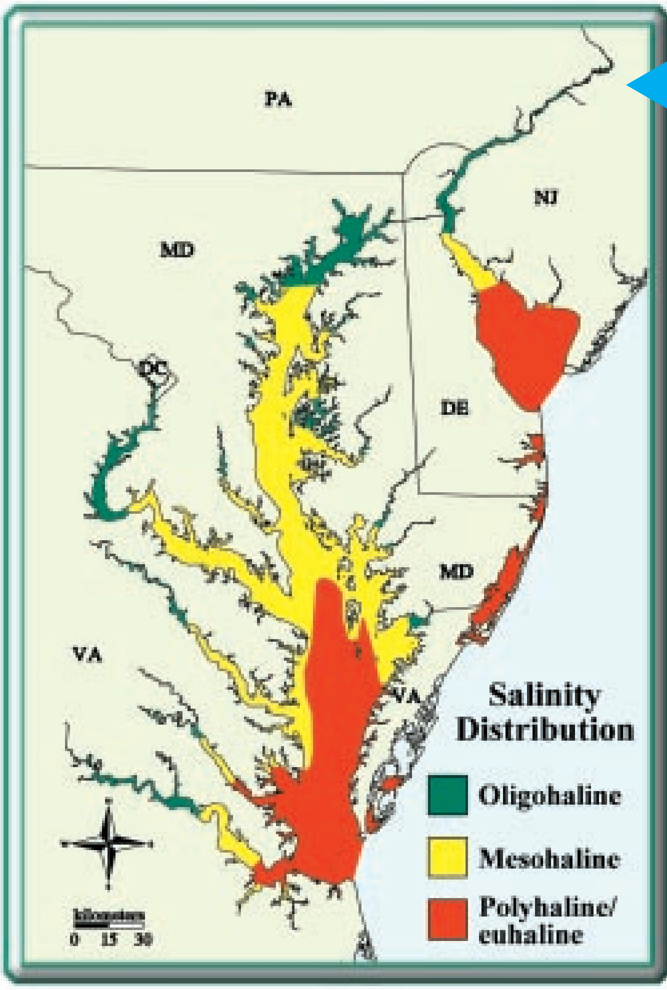


Figure 6. Summer salinity distribution in Mid-Atlantic bottom estuarine waters as observed in 1990-93. Categories are oligohaline (green), mesohaline (yellow), and polyhaline/euhaline (red).
Sources: Strobel *et al.*, 1995; Paul *et al.*, 1997

number of grams of dissolved salts in 1,000 grams of water. Salinity measurements in estuarine waters range from less than 0.5 ppt in fresh water to 5 ppt in brackish water to 33 ppt in coastal ocean water. Because fresh water contains fewer salts, it is lighter (less dense) than sea water, and tends to remain at the surface in a stratified estuary.

Salinity distribution in the Mid-Atlantic estuarine waters during the summer is summarized by three salinity categories: salinity less than 5 ppt (oligohaline waters), between 5 and 18 ppt (mesohaline waters), and greater than 18 ppt (polyhaline/euhaline waters). Bottom water salinity data for the summer is depicted in Figure 6. Oligohaline waters represent a small fraction of the estuarine area of the region. Mesohaline waters are dominant in Chesapeake Bay, while the Delaware Estuary and Delmarva coastal bays are mostly polyhaline waters.

Sediments are the materials deposited on the bottom of the estuary. They are comprised of sand, silt, and clay. The silt-clay (mud) content of sediments (less than 63 microns or 0.0025 inches particle diameter) is an important factor determining the composition of the biological ***community*** that inhabits the bottom sediments in estuaries. Although sediments are a natural part of estuarine ***ecosystems***, accumulation of excessive amounts of sediments is undesirable. Accumulated sediments can fill in ports and waterways. Sediments suspended in the water column cause the water to become cloudy, or turbid, decreasing light available for plant growth and animal feeding. Further, as ***suspended sediments*** settle to the bottom, the sediments can smother bottom-dwelling plants and animals.

Sediments also can carry pollutants. Smaller or fine-grained sediment particles (silts and clays) have a relatively large surface area. Many pollutant molecules easily adsorb, or attach, to small particles. As a result, fine-grained sediments can adsorb metals, nutrients, oil, ***pesticides***, and other potentially ***toxic substances***. Thus, areas of fine-grained sediments can contain high concentrations of sediment-bound pollutants.

An example of a plume of water, heavily laden with suspended sediments, entering an estuary.
Photo by: Chesapeake Bay Program

Estuarine sediments are summarized by three categories: sediment with silt-clay content less than 20% (sand), silt-clay content between 20% and 80% (mix), and silt-clay content greater than 80% (muds). Sand is the primary sediment category found across estuaries in the region. The Delaware Estuary is dominated by sandy sediments, while Chesapeake Bay and the Delmarva coastal bays have a relatively uniform split across the categories. However, the estuaries tend to be sandier near their openings to the coastal ocean.

Clear waters are valued by society and contribute to the maintenance of healthy, productive biological communities. ***Submerged aquatic vegetation***, discussed in a later section, is sensitive to ***water clarity***. Water clarity in estuaries is influenced by biological processes (for example, ***phytoplankton blooms***); inputs of sediment and ***detritus*** from streams, rivers, and nonpoint source runoff; and resuspension of bottom sediments during intense water movement, such as storms.

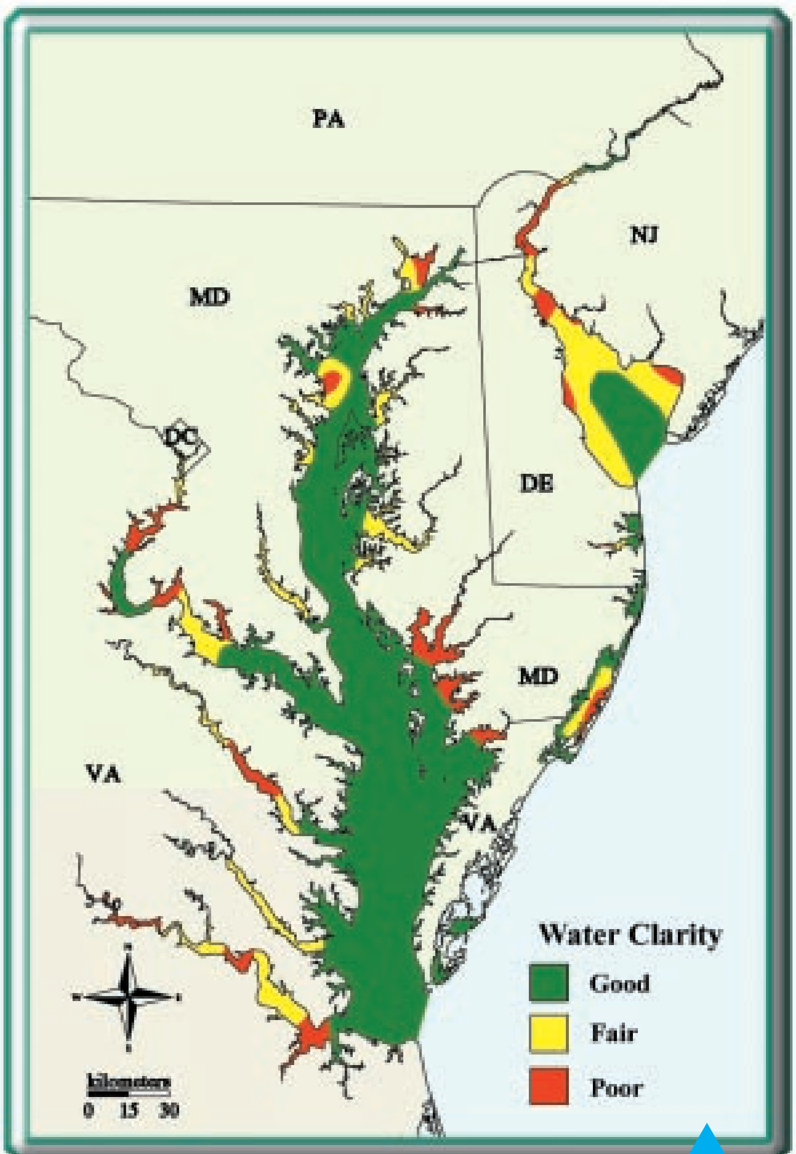


Figure 7. Summer water column clarity in Mid-Atlantic estuarine waters as observed in 1990-93. Water clarity categories are poor (red), fair (yellow), and good (green) and are defined in text and technical appendix.
Sources: Strobel *et al.*, 1995; Paul *et al.*, 1997

The clarity of estuarine water is determined by how far light can penetrate into the water. We define poor water clarity as water in which a diver would not be able to see his hand when held at arm's length. Fair water clarity corresponds to a wader not being able to see his feet in waist deep water. Most estuarine waters in the Mid-Atlantic Region have good water clarity (Figure 7). The degree of water clarity problems across the major subregions is related to the depths of the systems. Chesapeake Bay, being the deepest, has the overall highest water clarity. The shallow Delmarva coastal bays have the lowest. It should be recognized that not all water clarity problems are due to man's intervention. Wind mixing in shallow water resuspends sediments and decreases water clarity.

This overview of estuarine resource characteristics in the Mid-Atlantic Region sets the context for describing the state of the estuaries. For example, many factors underlie the changes in fish abundance, sizes, and species composition in estuaries. Among these factors are ***turbidity*** (water clarity) from resuspension of sediments, surface runoff, and phytoplankton growth; salinity; depth; and temperature. Susceptibility of fish to poor water quality is, in part, determined by estuarine characteristics. The next chapters provide our snapshot of the state of the estuarine environment in the Mid-Atlantic Region. They summarize what we know about a set of indicators, or measures, of estuarine condition for water and sediment quality, habitat change, condition of living resources, and aesthetic quality. Each indicator is briefly discussed relative to its importance for understanding estuarine condition, then summarized as to current condition using data from the early to mid 1990s. The final chapter in this report is our attempt to bring together the current conditions into an overall evaluation of estuarine condition.

Water Quality

Nutrients

All plants and animals need small amounts of ***nutrients,*** such as nitrogen and phosphorus, to grow and reproduce. However, an excess of nutrients can lead to ***eutrophication***, a condition in which prolonged blooms of algae rob light and oxygen from other organisms while turning waterways green and foul smelling. The concentrations of dissolved nutrients measured during the summertime are shown in Figure 8. The highly urbanized Delaware Estuary exhibits some of the largest concentrations of nutrients measured anywhere in the

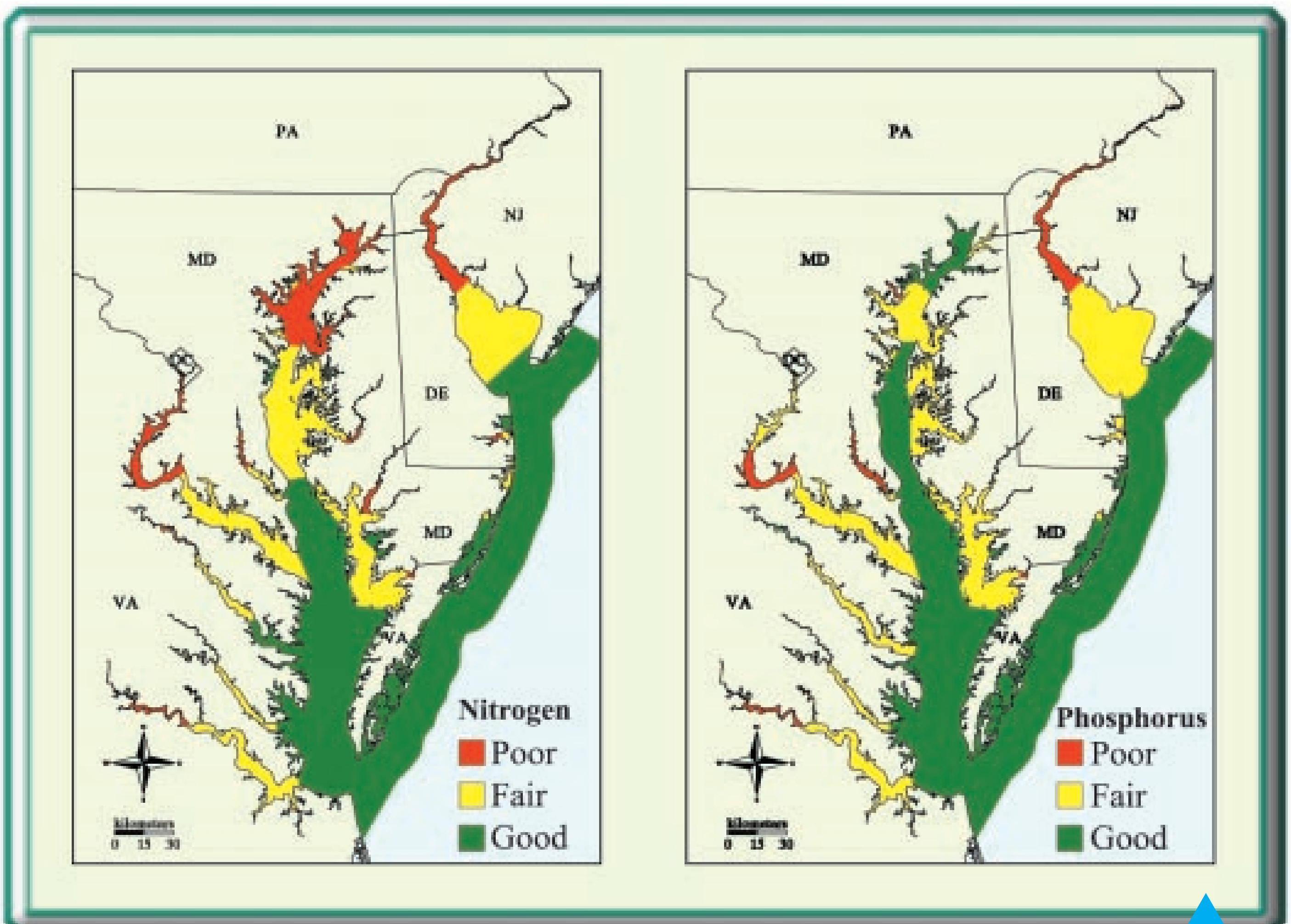


Figure 8. Concentrations of dissolved inorganic nitrogen and phosphorus measured during the summer months in surface waters. Nutrient levels are higher than optimum in most of the rivers and upper bays. The categories are defined and discussed further in the technical appendix.
Sources: Chesapeake Bay Program; Delaware Estuary Program; Bohlen and Boynton, 1996; Chaillou *et al.*, 1996

world. Nutrient levels are high in the upper bay and most ***tributaries*** of Chesapeake Bay, more so for nitrogen than phosphorus. The northern coastal bays are more enriched than the southern bays, reflecting the population and development trends in coastal Delaware and Maryland. Nutrient levels in the coastal waters are relatively low.

Nutrient overenrichment does not automatically lead to eutrophication. Other factors such as water clarity and salinity also play a role (refer to the technical appendix for more information). In the following section on phytoplankton, we examine a surprising illustration of this complex phenomena.

Nutrients can originate at either ***point sources*** (highly localized spots such as sewage treatment plants and industries) or ***nonpoint sources*** (more diffuse regions such as leaking septic systems, farmlands, lawns, and the atmosphere). A loading rate is the quantity of nutrients delivered by humans each year to each acre of estuary. This is a measure of the intensity of a nutrient source. Figure 9 compares the point and nonpoint loading rates of nitrogen and phosphorus in the major estuaries.

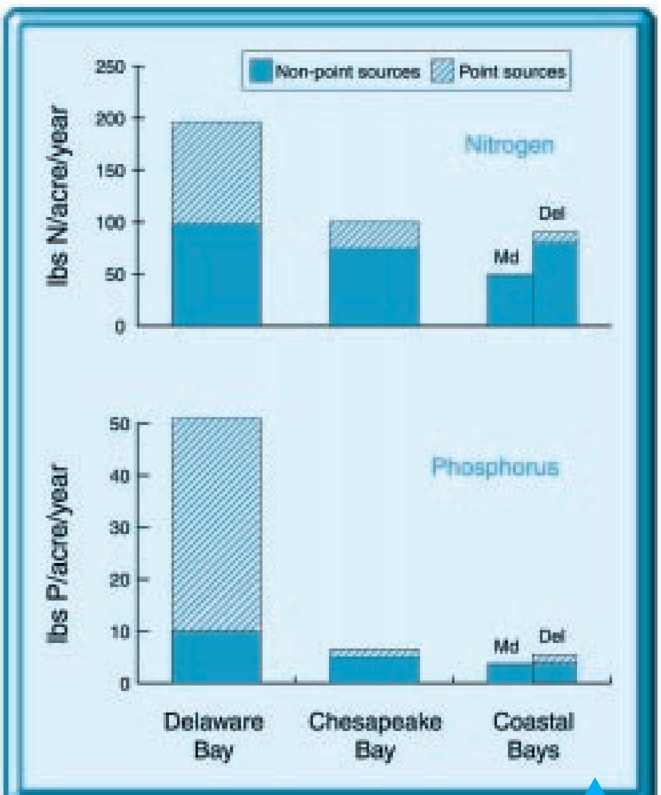


Figure 9. Nutrient loading (quantity of nutrients per acre per year) for the Mid-Atlantic estuaries in the early 1990s. Loads to the Delaware Estuary are high. Point sources are relatively well-controlled, except in the Delaware Estuary.
Sources: Chesapeake Bay Program; Bohlen and Boynton, 1996; Pennock *et al.*, 1994; Cerco *et al.*, 1994

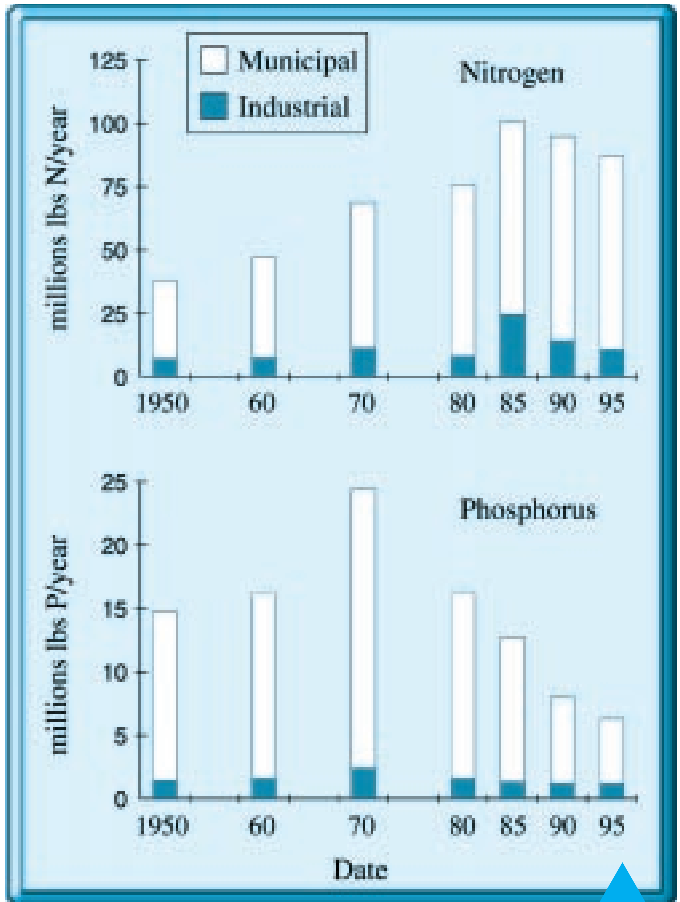


Figure 10. Trends in the quantities of nutrients delivered to Chesapeake Bay from point sources since 1950. Recently, the nutrient loads have been decreasing. Municipal sources are much greater than industrial sources.
Sources: Chesapeake Bay Program

It is clear from Figure 9 that the Delaware Estuary suffers the greatest loads. In part, this reflects the fact that this region is highly urbanized, but the loads also are high because of comparatively large contributions by point sources. Fortunately, point sources are relatively easy to identify and control; therefore reductions in the high loads to the Delaware Estuary are possible. Elsewhere, remediation programs must focus on controlling the more diffuse nonpoint sources such as runoff from city streets and farms and deposition from the atmosphere.

Figure 10 shows the quantities of point-source nutrients delivered to Chesapeake Bay since 1950. Cities and towns contribute far more nutrients to the bay than do industries. Phosphorus releases declined steadily since 1970 when the Clean Water Act became law and a phosphate detergent ban was implemented. Control of nitrogen discharges is more difficult, but progress is evident following the upgrading of sewage treatment plants.

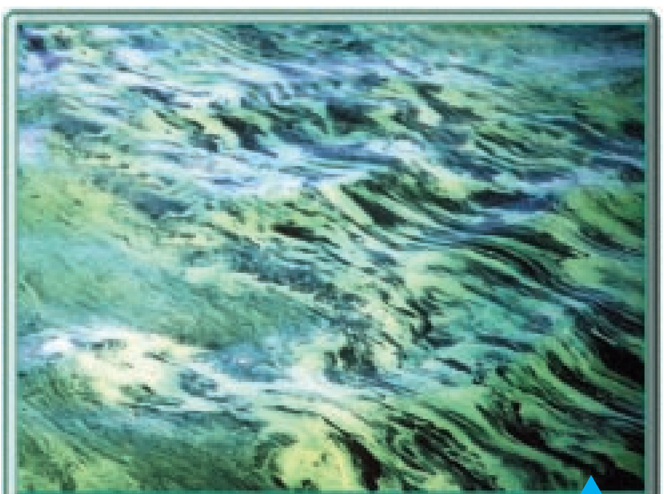
In summary, large portions of the region's estuaries are nutrient over-enriched, especially in tributaries and near urban centers. Efforts to reduce nutrient levels must focus on controlling nonpoint sources in all watersheds and point sources in the Delaware Estuary. Encouragingly, long-term trends are showing signs of improvement in response to environmental protection programs.

Phytoplankton

Phytoplankton blooms

Like plants everywhere, estuarine plants convert sunlight and nutrients through photosynthesis into food. Although bay grasses and ***macroalgae*** are common in some shallow sites, ***phytoplankton*** (tiny floating algae) are by far the most common plants in Mid-Atlantic estuaries. Paradoxically, these phytoplankton communities are unnoticeable most of the year because they are eaten as quickly as they grow. However, phytoplankton can bloom profusely for a few days or weeks when growth conditions are optimal. These blooms are part of the normal cycle in healthy estuaries (see sidebar). However, if extra nutrients are continuously available, as is often the case in estuaries near urban areas and farms, the blooms can persist longer, sometimes for the entire summer. Such unbalanced plant growth caused by excess nutrients is called eutrophication.

Prolonged phytoplankton blooms in ***eutrophic*** estuaries are detrimental for several reasons. Dense growths of the algae cloud the water and rob light from sensitive



Phytoplankton bloom in an estuary. If the bloom is persistent, the green algal mats can block light to other plants and deprive animals of oxygen. Area shown is about 5' x 6'.

***Photo by*:** U.S. Chesapeake Bay Program

Phytoplankton Blooms

As with all plants, phytoplankton need light and nutrients to grow and reproduce. However, neither component is available year-round in Mid-Atlantic estuaries. Sunlight is limited during the winter, and nutrients normally are in short supply during the summer and fall. A large 'spring bloom' occurs when the increasing sun angle delivers enough light for the dormant algae to begin using the abundant nutrients available from the well-mixed wintertime waters. Smaller blooms occur throughout the summer when storms mix the water, bringing nutrients from the bottom into the sunlit surface waters where the phytoplankton reside. In a healthy system, the blooms are short-lived because nutrients quickly become depleted, and the population of ***zooplankton*** (microscopic plant-eating animals) explodes to graze the phytoplankton crop. ***Crustaceans***, insects, and small fish then eat the zooplankton, and larger fish eat these organisms, *etc.* The estuary is fed and the murky waters clear until the next bloom. However, this balanced cycle is disrupted if extra nutrients are available. Phytoplankton (and in some places the macroalga, *Ulva*) then bloom continuously, clogging the estuaries with uneaten and decaying plant material.

beds of submerged aquatic vegetation (SAV), which are underwater grassy regions that are critical habitats for many other estuarine organisms. The massive losses of SAV in Chesapeake Bay during the 1960s were attributed to such persistent blooms. Blooms upset the ecological balance of estuaries by altering normal food webs and encouraging the spread of exotic or toxic plants at the expense of native species. Moreover, the dying blooms generate unpleasant odors and consume dissolved oxygen that would otherwise support the respiration of fish and bottom-dwelling organisms, forcing these organisms to move away or die.

To estimate phytoplankton abundance in estuaries, biologists measure the concentration of ***chlorophyll*** suspended in water. Chlorophyll is the green pigment present in all plants. Figure 11 compares summer chlorophyll levels throughout the Mid-Atlantic Region estuaries. A rating of 'good' designates healthy crops of algae, while 'poor' indicates the likely occurrence of blooms persistent enough to harm sensitive SAV beds.

Figure 11 shows that the largest levels of chlorophyll are found in the tributaries and upper regions of Chesapeake Bay. The coastal bays are moderately eutrophic, with particularly high levels of phytoplankton measured in several tributaries and man-made canals. Generally, these chlorophyll patterns closely follow the patterns of nutrient availability seen in Figure 8. In contrast however, the lower Delaware Estuary shows little indication of eutrophication despite the very high levels of nutrients found there (see sidebar). The coastal waters show low levels of chlorophyll, as is normal for these coastal regions.

Historically, eutrophication has decreased remarkably in parts of Chesapeake Bay. For instance, chlorophyll concentrations in the upper and middle Potomac Rivers are now about one fifth the levels evident in the 1970s and 1980s when foul-smelling mats of algae bloomed in response to high nutrient concentrations. Presently, blooms occur in the Chesapeake and coastal bays after periods of intense rainfall, probably in response to nutrients in runoff from farms and city streets. In the coastal bays, eutrophication is increasingly noticeable in the Indian and St. Martin's Rivers and in canals along developed shorelines.

Where are all the phytoplankton?

Surprisingly, the Delaware Estuary shows relatively low levels of chlorophyll despite the very abundant quantities of nutrients available in the bay. Why are summertime algal blooms infrequent? In part, the answer involves the fact that the bay is muddy. Because the Delaware basin is broad and shallow, the sediments are easily stirred by the winds and tides. Erosion from farms deposits additional sediment loads. The resulting low light levels in the water keep potentially harmful blooms in check. Ironically, managers are now concerned that improved land management practices might clear the water enough to permit eutrophication in the bay.

Despite recent improvements, most tributaries still are threatened by eutrophication. Chlorophyll-rich regions (bloom areas) generally mirror patterns of nutrient over-enrichment, except in the Delaware Estuary where murky water inhibits persistent algal blooms. In most cases, decreasing the sources of nutrients is a viable solution to eutrophication.

Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental requirement for the maintenance of balanced populations of fish, shellfish, and other aquatic biota. The nature and extent of an organism's response to ***hypoxia*** (low dissolved oxygen concentrations) depend on several factors, including the concentration of oxygen in the water, the duration of the organism's exposure to reduced oxygen, and the age and physiological condition of the organism. Most estuarine animals can tolerate short exposures to reduced dissolved oxygen concentrations without apparent adverse effects. Prolonged exposures to moderate hypoxia, defined as DO below 5 milligrams of oxygen per liter of water (mg/L, or parts per million), may result in altered behavior, reduced growth, adverse

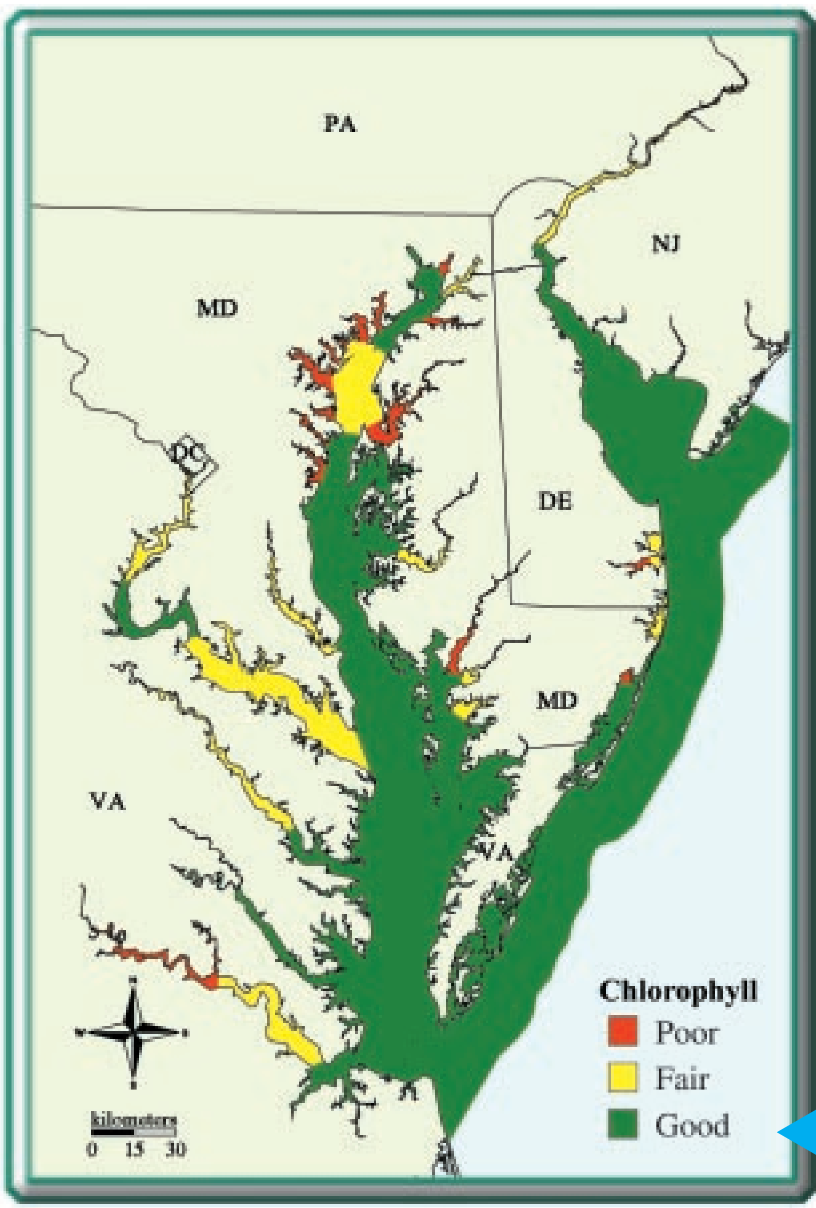


Figure 11. Chlorophyll concentrations (a measure of algal abundance) measured during the summer season in surface waters. The chlorophyll patterns mirror nutrient distributions, except in the Delaware Estuary. Categories are defined in the technical appendix.

Sources: Chesapeake Bay Program; Delaware Bay Estuary Program; Bohlen and Boynton, 1966; Chaillou *et al.*, 1996 reproductive effects, and possible mortality to sensitive species and juveniles. Some aquatic animals may avoid low dissolved oxygen waters. This behavior may result in increased predation and decreased access to preferred feeding areas or spawning habitat. In addition, aquatic populations exposed to low dissolved oxygen concentrations may be more susceptible to adverse effects from other stresses, such as disease and toxic substances. Severe hypoxia (DO below 2 mg/L) results in death to most aquatic animals, especially during summer months when metabolic rates are high.

As discussed in the prior section on ***"Nutrients"***, nitrogen and phosphorus fuel the growth of phytoplankton (see Figure 12). The nutrients enter the estuarine waters primarily through wastewater discharges, agricultural and urban runoff, and ***atmospheric deposition***. Decomposition of dead algae consumes oxygen, which reduces the dissolved oxygen available to support aquatic life. Algal growth increases with light and temperature, and decomposition also speeds up with elevated temperatures. Vertical stratification in estuarine waters (warmer, fresher water over colder, saltier water) during the late spring to summer period restricts reoxygenation of bottom waters. The amount of oxygen that can remain dissolved in water is reduced as temperatures increase. Therefore, natural processes that occur in estuarine waters set the stage for maximum reductions of dissolved oxygen in bottom waters during the late summer.

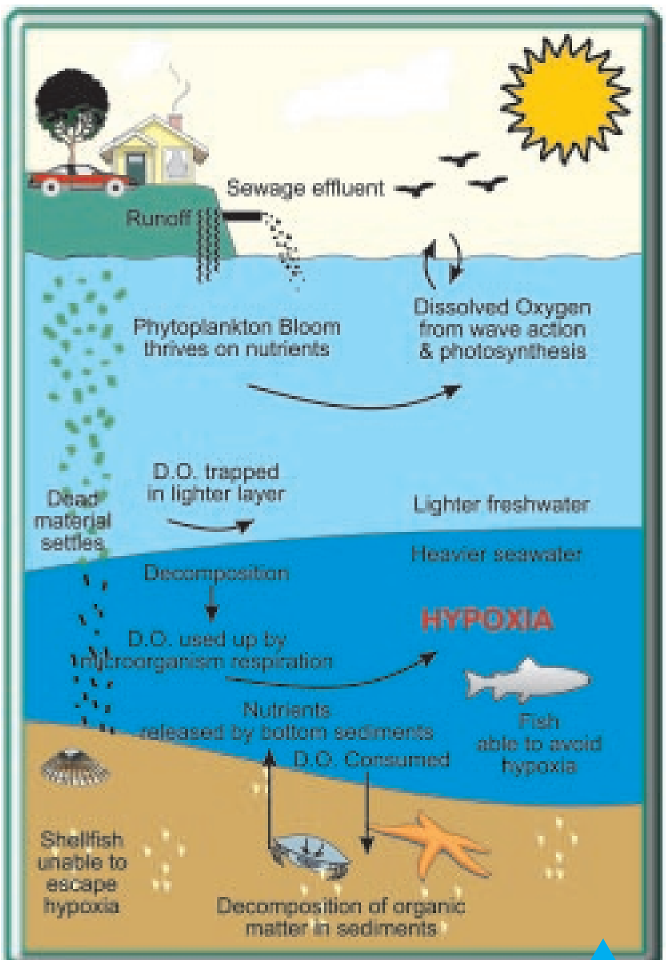
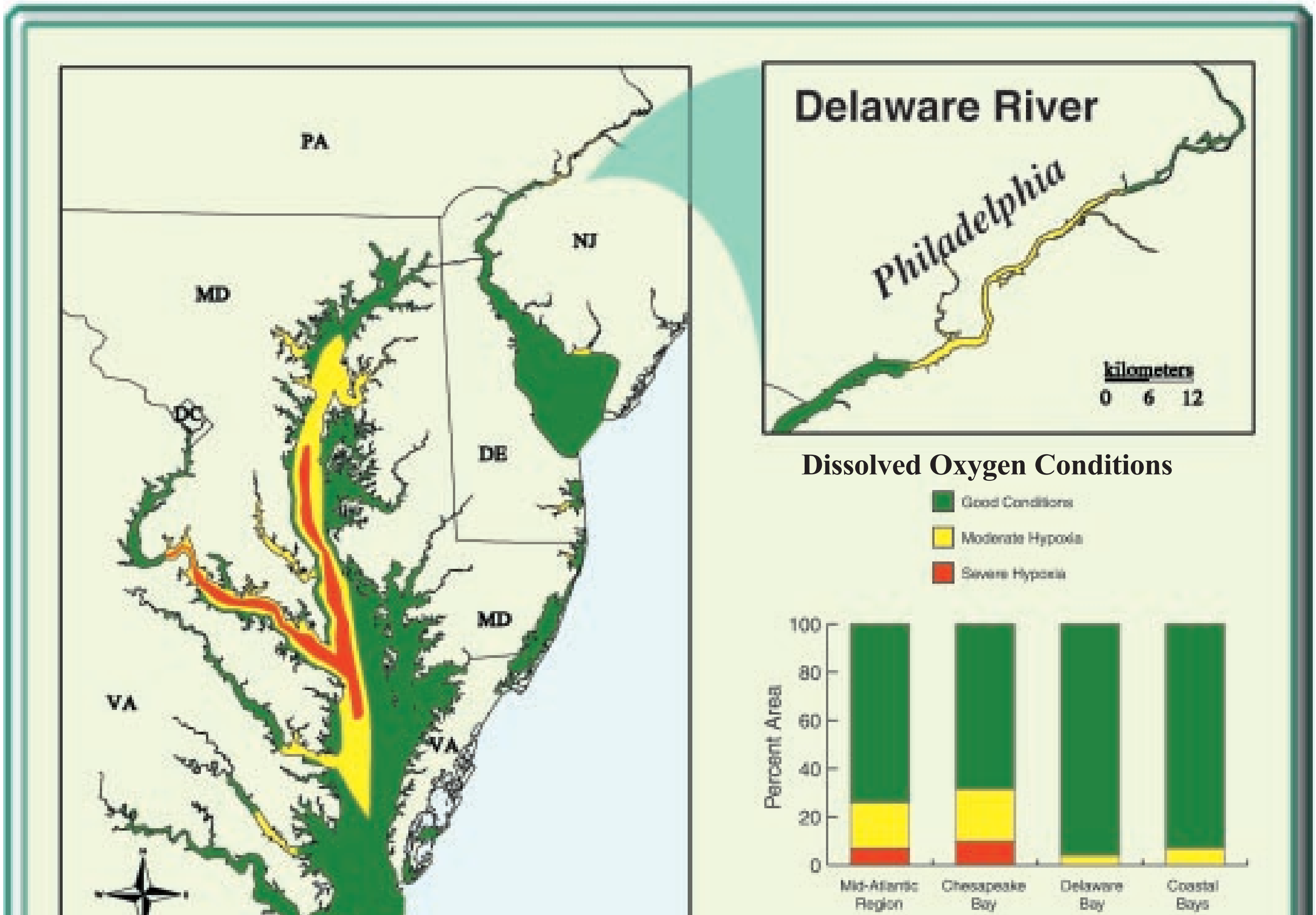


Figure 12. Physical, chemical, and biological processes affecting dissolved oxygen (DO) in estuarine waters that can result in hypoxia (low DO).
Source: Redrawn from USEPA, 1992

Factors Affecting Dissolved Oxygen Levels

The amount of oxygen available to estuarine organisms is affected by salinity and temperature. Cold water can hold more dissolved oxygen than warmer water, and fresh water holds more than salt water. The concentration of dissolved oxygen varies with location and time of day. Oxygen is transferred from the atmosphere into the surface waters by diffusion and the aerating action of wind. It is also added as a by-product of photosynthesis. Floating and rooted aquatic plants and phytoplankton release oxygen as part of photosynthesis. Because this process requires light, production of oxygen is limited to shallow water areas, usually less than 6 feet deep. Surface water is nearly saturated with oxygen most of the year, while deep bottom water ranges from saturation to ***anoxia*** (no oxygen present).

The summer distribution of DO within one meter of the bottom across the Mid-Atlantic estuarine area is shown in Figure 13. Dissolved oxygen conditions are summarized by three categories: good, with DO greater than 5 mg/L (green); moderate hypoxia, with DO between 2 and 5 mg/L (yellow); and severe hypoxia, with DO less than 2 mg/L (red). During the summer, 17% of the estuarine bottom waters are moderately hypoxic, and 8% are severely hypoxic. Chesapeake Bay exhibits the most hypoxia, with 21% of its area between 2 and 5 mg/L, and 10% below 2 mg/L. These areas in Chesapeake Bay are located in the middle portion of the Bay, the lower portion of the Potomac River, and the Patuxent, Patapsco, Chester, Rappahannock, and York Rivers. Many of these areas are stratified and are continuously depleted of DO during the summer months rather than experiencing a cyclic condition where low dissolved oxygen occurs only late at night, when photosynthesis is not replenishing the oxygen. Because the data depicted in Figure 13 were derived from daylight hours observa-



Graph Sources: Strobel *et al.*, 1995; Paul *et al.*, 1997

Map Sources: Chaillou *et al.*, 1996; CBP, 1997; USEPA, 1995; Magnien *et al.*, 1993; Strobel *et al.*, 1995; Paul *et al.*, 1997

Figure 13. Distribution of summer-time dissolved oxygen within one meter of bottom sediments across estuarine waters in the Mid-Atlantic Region. Categories are defined in the technical appendix. Data were derived from daylight observations and do not necessarily reflect night time depressions that may occur in some areas. Map depicts spatial distribution derived from multiple sources of information. Bar graph shows percent areas derived from EPA EMAP 1990-93 data.

tions, the extent of depleted DO conditions in the Delmarva coastal bays may not be properly characterized. Strongly associated with decreasing levels of dissolved oxygen is the poor condition of bottom-dwelling organisms. While other environmental stresses also appear to affect bottom organisms, low levels of dissolved oxygen most often co-occur with poor conditions of bottom-dwelling animals in estuarine waters of the Mid-Atlantic Region.

Sediment Contamination

Potentially toxic substances reach estuaries from industrial and municipal ***effluents***, storm water runoff, and atmospheric deposition. Many types of contaminants pose a potential threat to estuarine waters. These contaminants include ***trace metals*** (chromium, copper, lead, mercury, silver, arsenic, zinc) and organic compounds such as ***PAHs (polycyclic aromatic hydrocarbons), PCBs (polychlorinated biphenyls)***, and pesticides such as ***DDT***, Chlordane, and atrazine. Most of these contaminants bind to particles suspended in the water and settle to the bottom; therefore, their concentrations in sediments typically are much higher than in the overlying waters. Measuring toxic substances in estuarine sediments is an efficient method of determining ***contamination*** levels in estuaries and identifying areas that may require further evaluation.

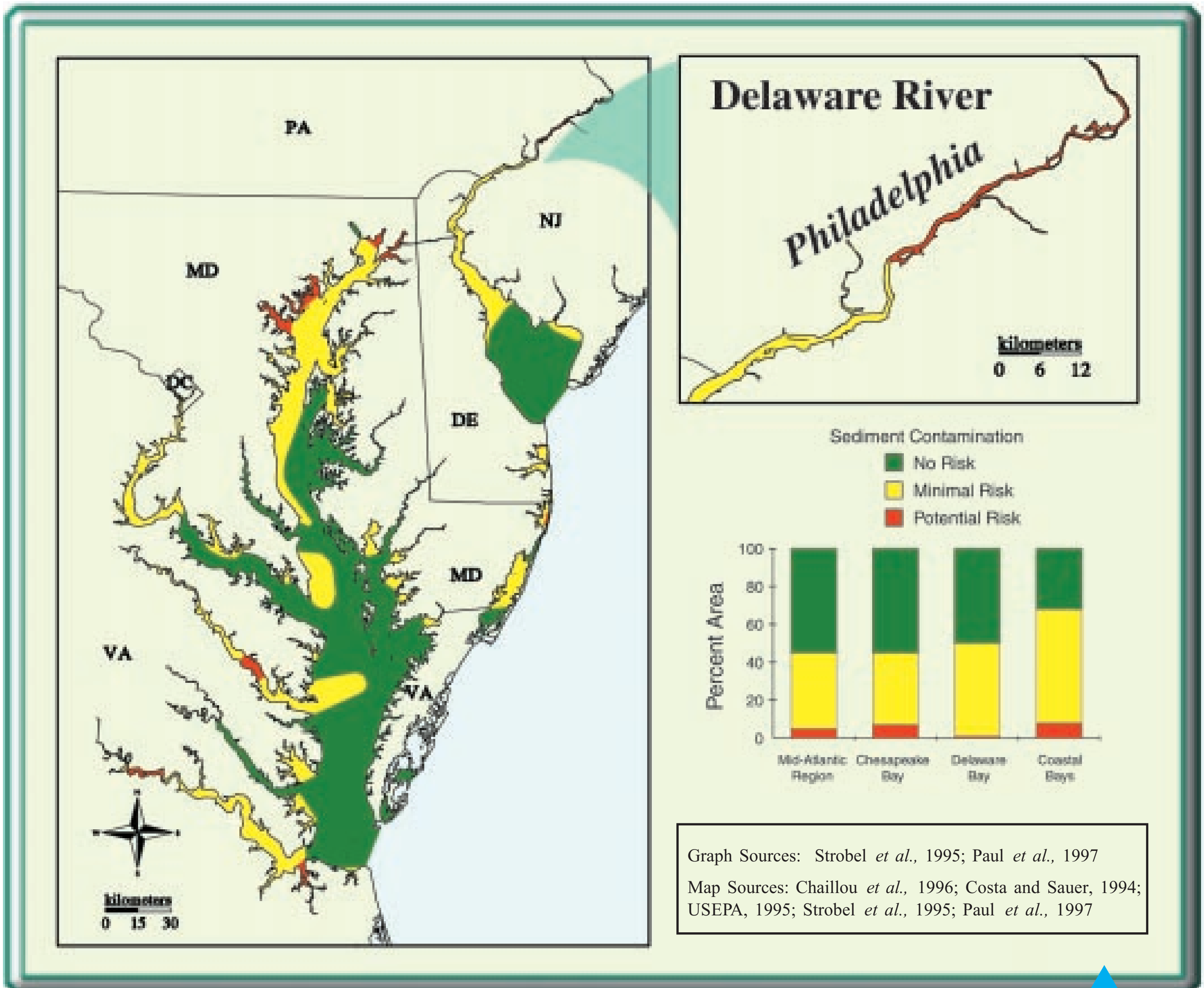
Contaminated sediments and their potential toxicity to aquatic life are considered by the public as a major threat to estuaries. Contaminated sediments often are considered an indicator of poor estuarine condition even if the sediments are not presently toxic to estuarine plants and animals. The concentration in the sediment at which a contaminant becomes toxic depends on the species and life stages of the organisms present, as well as the physical and chemical characteristics of the sediments and overlying waters. Due to the difficulties in determining toxic concentrations of trace metals, PAHs, PCBs, and pesticides, no state or federal regulatory criteria or standards exist to determine "acceptable" sediment concentrations of all these substances.

Sediment contaminant distribution across estuaries of the Mid-Atlantic Region is shown in Figure 14. Sediment contamination is categorized as sediments which pose no risk to aquatic life (green), minimal risk to aquatic life (yellow), and potential risk to aquatic life (red). Approximately 53% of the Mid-Atlantic estuarine sediments have sediment contaminant levels considered to pose no risk to

Potentially Toxic Contaminants

Trace metals naturally occur in the earth's crust. Their presence in estuarine sediments does not necessarily indicate contamination from human activities. Many of these metals are essential to organisms, in minute quantities, but if present in sufficiently high quantities they can become toxic. PAHs are organic compounds, like PCBs and many pesticides. They are released to the environment primarily through burning fossil fuels. Spills of petroleum compounds, including leaking oil from cars, also may cause environmental contamination.
Due to the widespread use of fossil fuels and the large number of vehicles, PAHs are now ubiquitous in the environment.

Contaminated sediments present a danger to the organisms living in or near them and to the consumers of these organisms.
Photo by: U.S. Fish and Wildlife Service



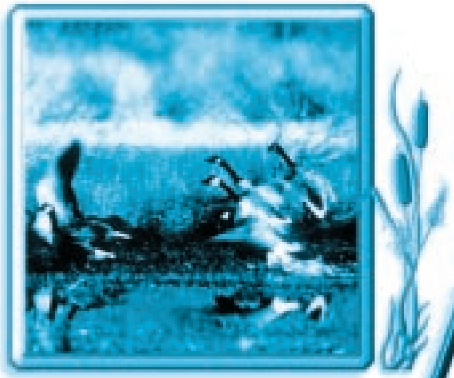
Graph Sources: Strobel *et al.*, 1995; Paul *et al.*, 1997

Map Sources: Chaillou *et al.*, 1996; Costa and Sauer, 1994; USEPA, 1995; Strobel *et al.*, 1995; Paul *et al.*, 1997

Figure 14. Distribution of sediment contamination across Mid-Atlantic estuaries expressed as risks to aquatic life. Categories are defined in the technical appendix. Map resolution is not in sufficient detail to indicate that the Anacostia River, a tributary to the Potomac River in Washington, D.C., has been identified as having potential risk from sediment contamination. Map depicts spatial distribution derived from multiple sources of information. Bar graph shows percent area derived from EPA EMAP 1990-93 data.

aquatic life. Only 6% of the sediments contain contaminant levels considered to pose a potential risk to aquatic life. These sediments are focused around the major industrial areas in the region, such as Baltimore and Philadelphia.

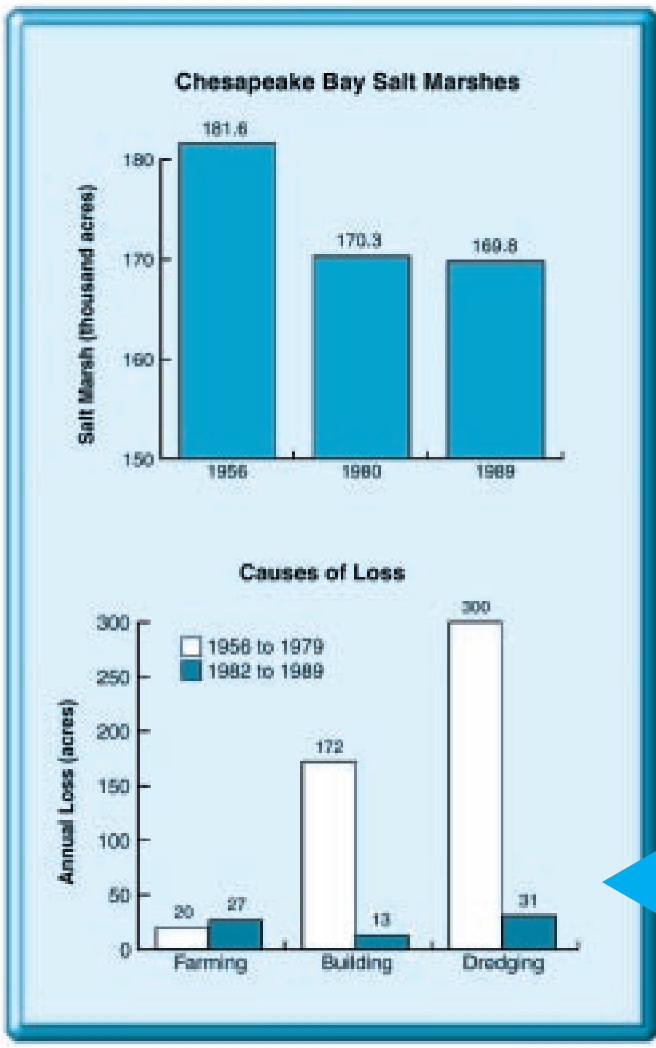
The sources of toxic substances include point sources (industrial and wastewater treatment plant discharges) and nonpoint sources including urban stormwater runoff (from streets, parking lots, and grassy areas), atmospheric deposition (directly on the water surface and on the land that eventually enters the estuary), and agricultural runoff. Urban stormwater runoff and point sources are the major sources for metals entering the estuarine waters of the Mid-Atlantic Region. The major sources for PAHs and PCBs are urban stormwater runoff and atmospheric deposition. Pesticide loadings to estuarine waters primarily are from agricultural runoff and atmospheric deposition. Recent studies by the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program indicate that sediment contaminant levels in the Mid-Atlantic Region generally have been decreasing over the last decade.



Habitat Change

Coastal Wetlands

Wetlands were once considered to be little more than the bothersome breeding grounds of mosquitoes and foul smelling gases. We now realize they are extraordinarily productive habitats that offer protective shelter and abundant food to juvenile fish, shellfish, migrating waterfowl, and thousands of other species, many of which are threatened or endangered. Coastal wetlands also buffer the coastline from severe storms and intercept nutrients and sediments that would otherwise interfere with the sensitive nutrient and light requirements of estuarine organisms.



Ecologists estimate that more than half of the region's original coastal wetlands have been lost because of human activities dating from pre-colonial times. Presently, about two thirds of the coastal wetlands are ***salt marshes*** colonized by salt-tolerant grasses and bushes. Much of the balance are ***tidal mud flats***, areas that are exposed at low tide and are densely packed with shellfish, invertebrates, crabs, and other organisms. The remainder are freshwater ***marshes***, forests, and shrublands.

Figure 15 presents information about recent changes in Chesapeake Bay salt marshes. From 1956 to 1989, about 6% of the region's wetlands were drained or filled to accommodate human needs. The practices responsible for most of these losses include pond construction, channelization for mosquito control, urban and rural development, and dredging for marinas. Conversion to agricultural lands, along with natural processes such as rising sea level and coastal subsidence, have contributed to wetland destruction as well. More recently, the loss rate has slowed in response to strict state and federal conservation plans and slowed development. Agricultural practices account for an increased portion of current losses. Similar trends are evident in Delaware Bay and the Delmarva coastal bays.

The near-term goal for the Mid-Atlantic Region is "no net wetland loss." This strategy implies that the remaining wetlands will survive as robust habitats able to provide shelter, food, and recreation for many organisms, including humans.

Figure 15. Trends in the acreage of salt marsh in the Chesapeake Bay region and the causes of loss over two recent time periods. Recently, the losses have stabilized, largely due to slowed development.
Source: Tiner *et al.*, 1994

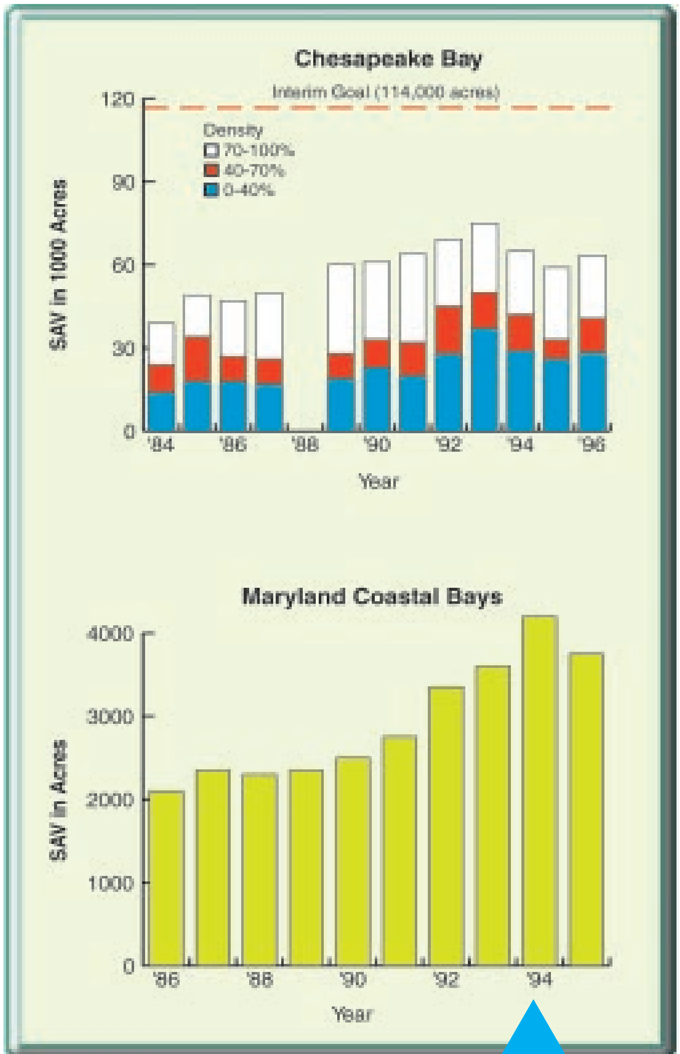


Figure 16. Recent changes in the coverage of SAV in the Chesapeake and Maryland coastal bays. An interim goal in the Chesapeake region is to restore sea grasses to all areas where they were observed prior to 1970 (about 114,000 acres) and to enhance bed densities.

Sources: Chesapeake Bay Program; Bohlen and Boynton, 1996

Submerged Aquatic Vegetation

The swaying meadows of bay grasses found in the shallow waters of the Chesapeake and coastal bays are called submerged aquatic vegetation or SAV. Bay grasses such as eelgrass and widgeon grass provide critical food, shelter, and nursery grounds for many species of waterfowl, shellfish, finfish, and other organisms. In one study, biologists found that SAV beds supported 30 times more young blue crabs than areas without grasses. The grasses also stabilize the shifting sediments and inject life-sustaining oxygen into the water. Unfortunately, this important resource is very sensitive to pollution. SAV is equivalent to the "miner's canary," warning of poor conditions in the bays.

More than many other plants, bay grasses need plenty of sunlight to grow. High levels of nutrients are detrimental because they can stimulate extended blooms of phytoplankton that block light to the SAV. Sunlight is further attenuated by runoff from farms and construction sites and by sediments suspended by storms and tides. SAV originally colonized over 600,000 acres of the Chesapeake and coastal bays. Only a tenth of that domain remains today.

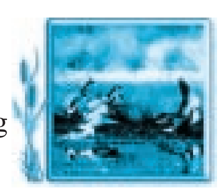
The reasons for these historical losses are quite different in the three estuary systems. The losses in Chesapeake Bay are blamed on phytoplankton blooms and nutrient over-enrichment, while the decline in the coastal bays is attributed to an excess of suspended sediments, in part associated with boating and construction. Eelgrass blight also decimated eelgrass beds

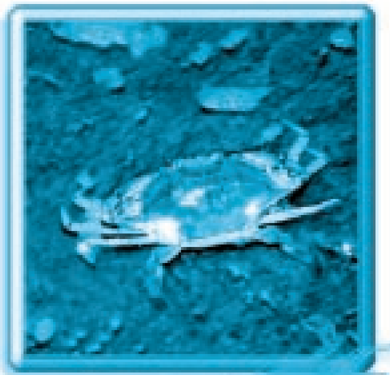
Submerged aquatic vegetation

Photo by: Robert Orth

throughout the Mid-Atlantic region in the 1930s. In contrast, Delaware Estuary probably never had extensive SAV beds because the water in this shallow bay is kept naturally murky by tides and storms. Clearly, restoration strategies for the estuaries must be tailored to the unique conditions of each bay. Figure 16 shows encouraging signs of SAV recovery. The colonized areas have doubled since the mid 1980s in the Chesapeake Bay and Maryland coastal bays. Presently, SAV beds are nearly absent from the Delaware Estuary and the Delaware coastal bays.

Wetland and SAV habitats are essential to the survival of all estuarine life. However, both resources are very sensitive to disruptions caused by humans. Loss of salt marshes has mostly been stabilized and the challenge now is to keep the remaining marshes healthy. SAV beds are slowly but steadily returning to their former ranges, largely in response to improved water quality.





Condition of Living Resources

Benthic Condition

Bottom dwelling animals or ***benthos*** are linked with other estuarine animals and plants through a network of interactions that preserves the health of the estuarine ecosystem. For example, benthic ***filter feeders*** promote a healthy ecosystem by filtering algae and sediment from the water, which helps maintain water clarity. That in turn promotes good plant growth required for a productive bottom ***community***. Benthic organisms are a critical component of the estuarine ***food web***, supporting many commercially important species of fish and shellfish.

Benthic organisms inhabit the bottom sediments where contaminants tend to accumulate and where the bottom waters are subject to low dissolved oxygen or fast currents. Many remain in one spot on the bottom or move relatively short distances over their life time. Therefore, the condition of the benthic community often is a good indicator of the condition of the local estuarine environment. Benthic communities have been shown to respond to human impacts in specific ways. A knowledge of these patterns helps us understand benthic conditions in relation to the factors acting on the bottom community.

Benthic Condition Index

The change in salinity from fresh water to the sea is the dominant factor determining the variety of benthic animals. Therefore, an index of benthic condition uses information on the variety of animals we expect to find at different salinities. This gives us an expectation for the condition of a healthy benthic community. Large-scale patterns of change in salinity are expected to cause large changes in the expected variety of species. However, if salinity remains the same and the number of species found in the benthic community is very different from that expected based on the salinity, we can be fairly certain that some other factor is causing this change. These departures can be caused by natural or human factors. The circumstances surrounding each case must be examined to determine what factors or combinations of factors are responsible.

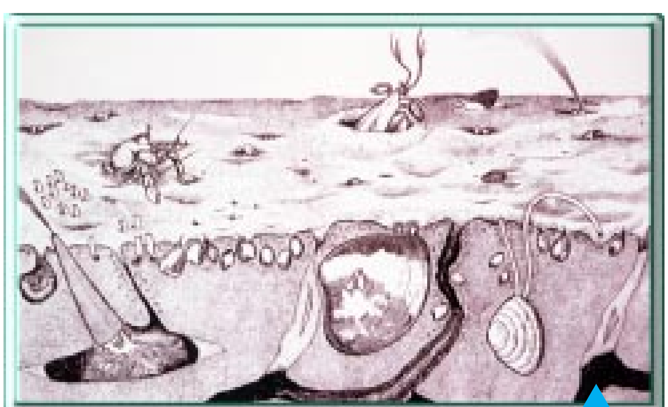


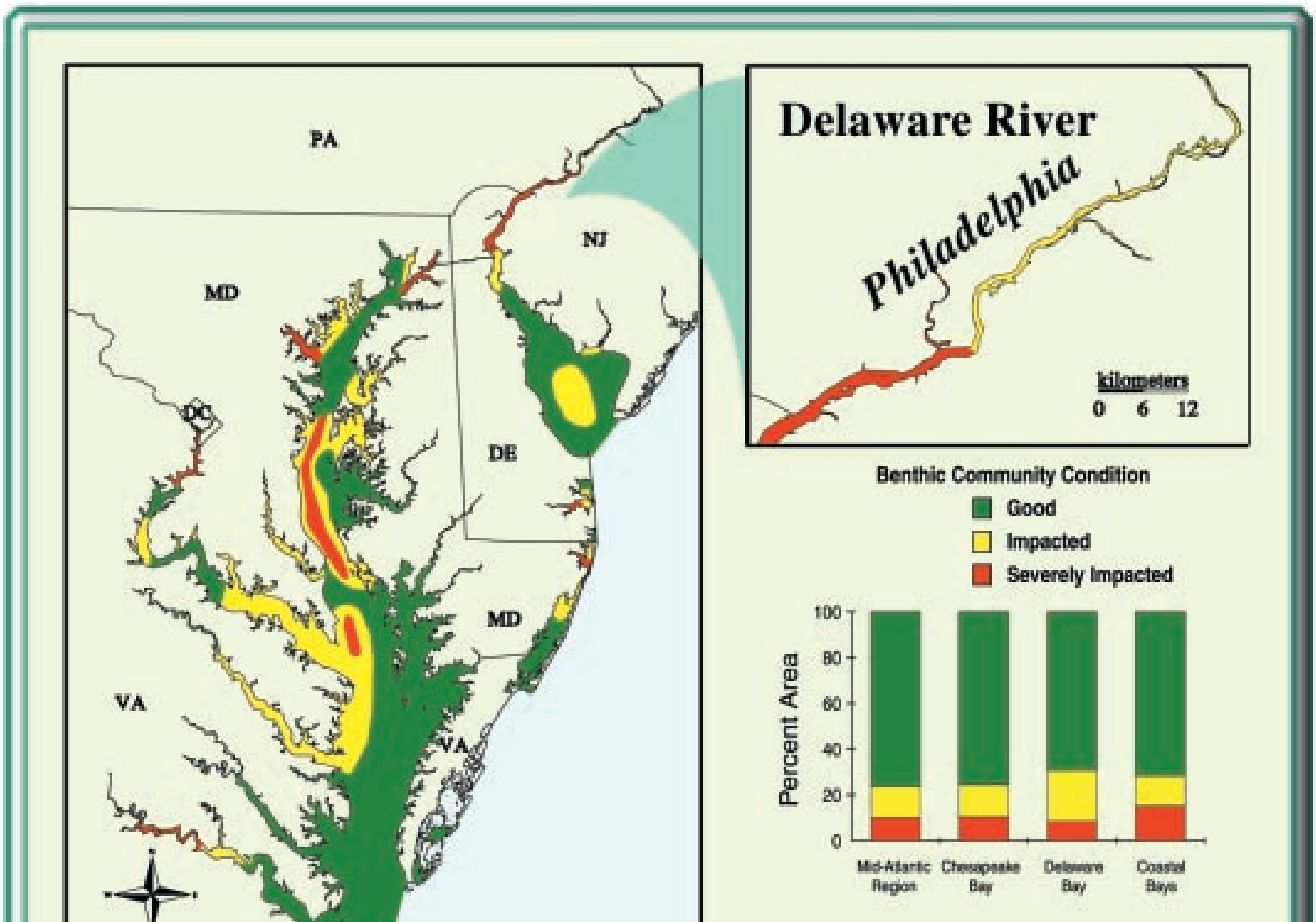
Illustration of a typical mud bottom benthic community.

Figure 17 displays the distribution of benthic community condition across the Mid-Atlantic Region. Impacted benthic condition refers to benthic communities determined to be in a degraded state. However, areas with impacted benthic condition may not be related directly to human effects because both ***anthropogenic*** and natural disturbances can cause effects.

The Delmarva coastal bays have impacted benthic communities in approximately one-fourth of their area. The Indian River is the most impacted; three-fourths of its area exhibit impacted benthic communities. Chincoteague Bay is the least impacted, with approximately 10% of the area exhibiting impacted benthic communities. Many of these impacted areas are associated with nutrient overenrichment.

About one-fourth of the Delaware Estuary has impacted benthic communities. The highest density of impact occurs in the Delaware River. Poor benthic conditions in the Delaware River are associated with levels of chemical contamination that commonly affect estuarine organisms. Some areas exhibiting impact in lower Delaware Bay occur where fast currents scour the bottom, while other areas appear to be affected by excess phytoplankton production due to nutrient overenrichment, resulting in increased levels of organic carbon in the sediments.

Approximately one-fourth of the area of Chesapeake Bay contains bottom sediment habitats with poor benthic communities. A large portion of this area (middle mainstem and lower Potomac and Rappahannock Rivers) is impacted by low dissolved oxygen conditions. Toxic contaminants are responsible for impacts in industrialized locations around the Bay. Small systems near Baltimore, Norfolk, and Washington, D.C. are areas where chemical contamination has affected the benthic communities. Localized areas of eutrophication also occur in some small embayments and estuaries and along some river reaches (*e.g.,* Pocomoke and upper Potomac Rivers). Natural stressors, such as highly variable salinity regimes, cause impacts in a few areas in Chesapeake Bay (*e.g.,* Elk River).



Graph Source: Strobel *et al.*, 1995; Paul *et al.,* 1997

Map Source: Chaillou *et al.,* 1996; USEPA, 1995; Strobel *et al.,* 1995; Paul *et al.*, 1997

Figure 17. Distribution of benthic community condition across estuarine waters in the Mid-Atlantic Region. Categories are defined in the technical appendix. Map depicts spatial distribution derived from multiple sources of information. Bar graph shows percent area derived from EPA EMAP 1990-93 data.

Overall, approximately one-fourth of the estuarine waters of the Mid-Atlantic Region exhibit impacted benthic communities. Many occur close to urban centers. Benthic communities dominated by species that are adapted to high sediment carbon concentrations occur in the Delaware Estuary, the Delmarva coastal bays, and in some small estuarine systems in Chesapeake Bay. The most prominent cause of impacted benthic communities in the Mid-Atlantic estuaries is low dissolved oxygen concentrations in the bottom waters. This problem is largely confined to Chesapeake Bay. Similar types of stressors on the benthic communities (*e.g.*, low dissolved oxygen, chemical contamination, eutrophication, high velocity currents, dredging, and trawling) occur in each of the Mid-Atlantic estuaries; however, the relative importance and magnitude of the effects caused by each stressor are different across the estuaries.

Shellfish Harvest

The annual oyster harvest for Mid-Atlantic estuaries has been as high as 133 million pounds (in 1880, Figure 18). Today's annual catch of about one million pounds is only a small fraction of past harvests. Most of the bottom of the Virginia portion of Chesapeake Bay is classified as potential oyster ground. These areas did support populations of oysters in the past; however, today the only productive ground left in lower Chesapeake Bay is the middle portion of the James River, Virginia.

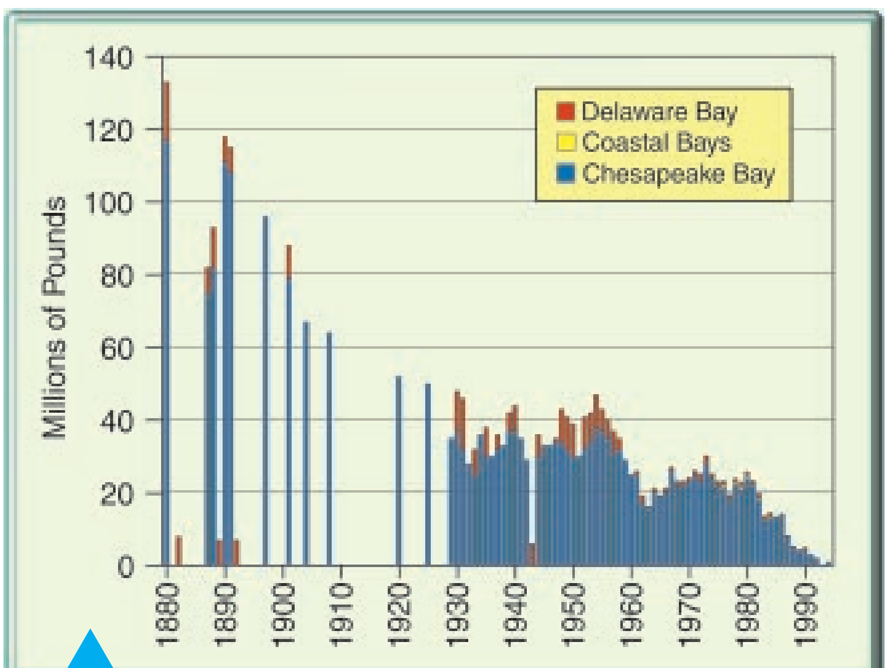


Figure 18. Annual oyster harvest for Mid-Atlantic estuaries. Gaps in the late 1880s and early 1900s do not represent zeros, but rather missing data.

Sources: NOAA/NMFS; Chesapeake Bay Program; Haskin Shellfish Lab; Lyles, 1967a,b

The American Oyster

Shellfish, specifically the American oyster, *Crassostrea virginica,* have traditionally been one of the major living resources harvested in the Mid-Atlantic states. Today oysters are the most seriously threatened. The oyster has played an important role in both the economics of the area and the ecology of the estuaries. Oysters prefer shallow water with a hard ***substrate*** and are tolerant of salinities ranging from approximately 5 ppt to over 30 ppt, meaning they are well suited to much of Chesapeake Bay, the Delaware Estuary, and the Delmarva coastal bays.

As will be discussed in a later section, disease, specifically ***Dermo*** and ***MSX***, appears to be one of the major causes of the recent drastic decline in oyster populations in the Chesapeake and Delaware Bays. Over-harvesting and pollution also play major roles in Chesapeake Bay. The impact of these diseases extends beyond their direct effects on native populations of oysters. The oyster is a ***filter feeder***, meaning it pumps water through its gills for both respiration and feeding. As it pumps this water, the gills filter out particulates, including phytoplankton, from the water. It has been estimated that the pre-1870 population of oysters in Chesapeake Bay could filter the entire water column of the Bay in a few days. This suggests they played a major role in clarifying the water of the Bay, allowing more light to reach the bottom where SAV grows. Because of the drastic decline in the number of oysters in Chesapeake Bay, it now takes about 11 months for this filtering to occur. The loss of this filtering capacity can profoundly effect the ecosystem and may have contributed to the decline in SAV.

Although no immediate solution to the problem is known, researchers are working on the concept of introducing disease-resistant strains of oysters to Mid-Atlantic estuaries (see ***"Incidence of Disease"*** section).

With the decline of the oyster industry, the most important shellfish industry in the Mid-Atlantic Region is now the blue crab *(Callinectes sapidus)* fishery. As oysters have disappeared from the waters of major Mid-Atlantic estuaries, many oyster fishermen have switched to fishing for blue crab. This has significantly increased the fishing pressure on a population that already was heavily exploited (approximately 75% of the adult crabs of Chesapeake Bay are harvested yearly). Over the past 40 years there has been a five-fold increase in the Virginia Chesapeake Bay blue crab fishing effort. An increase also has been seen in the Delaware Estuary. New Jersey issued permits for 3,001 crab pots for the Delaware Estuary in 1969. By 1993, that number had risen to 40,688 pots.

Annual harvest of the blue crab has been variable over the past decades (Figure 19). This variability likely is due to natural environmental factors compounded by fishing pressures. Environmental conditions play an important role in the condition of crab stocks. The low catch experienced in 1977 and again in 1981 in the Delaware Estuary has been attributed to unusually severe winters in which ice conditions resulted in high mortality among over-wintering crabs. Another major factor is the speed and direction of surface currents during spawning season. Females typically travel "down bay" into the higher salinity waters to release eggs. The ***larvae*** are photo-positive, meaning they are attracted to light and, therefore, reside in the surface waters. Wind-generated currents may carry the larvae back into the bay, resulting in increased populations. Different wind patterns may carry the larvae out to sea, causing lower catches in subsequent years. Another important factor contributing to the decline in crab populations is the loss of habitat, specifically beds of submerged aquatic vegetation that provide shelter for juvenile crabs. As discussed in an earlier section, there has been considerable loss of SAV in Mid-Atlantic estuaries.

Blue crabs harvested from Mid-Atlantic estuaries

Photo by: Chesapeake Bay Program

Although the blue crab catch in Chesapeake Bay and the Delaware Estuary remains about average, the ***catch per unit effort*** (number of crabs caught per pot per day) has decreased. Some scientists believe the harvest is being kept up by increasing effort, not stable populations. Over the past several years the blue crab harvest in the coastal bays has been minimal, predominantly due to disease, which has significantly reduced blue crab populations in these estuaries.

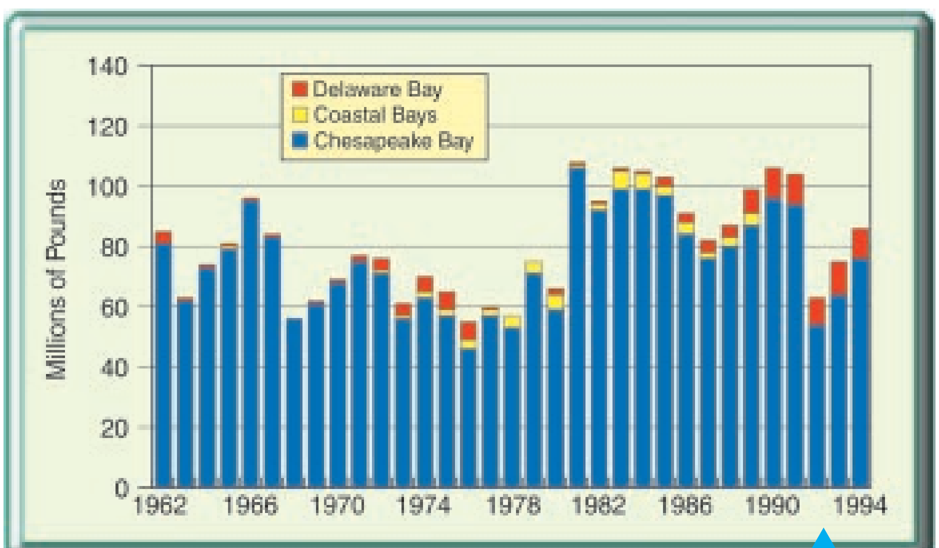


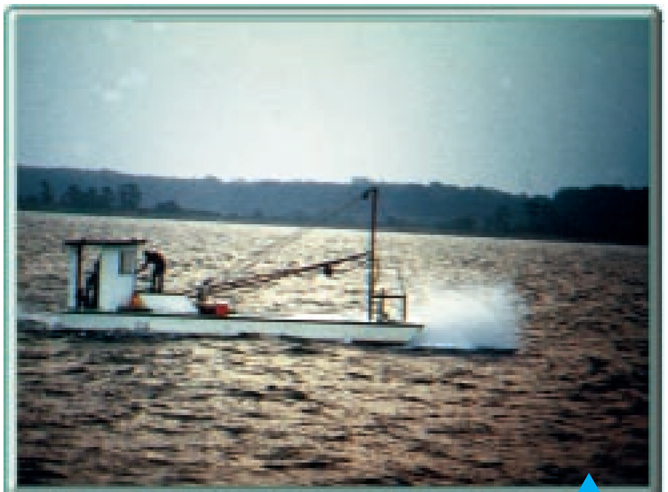
Figure 19. Annual blue crab harvest for Mid-Atlantic estuaries.

Sources: NOAA/NMFS; Chesapeake Bay Program; Lyles, 1967a,b

Scientists are concerned that consecutive years of poor environmental conditions combined with heavy fishing pressures could result in such a serious impact on blue crab populations that it would be difficult to recover. To avoid such a situation, both Virginia and Maryland have placed restrictions on crabbing in Chesapeake Bay waters. New Jersey and Delaware also have taken steps to protect the fishery in the Delaware Estuary, limiting the number of commercial licenses issued and placing restrictions on the collection of egg-bearing female crabs.

Shellfish Closures

Each state monitors their estuarine waters for ***coliform bacteria*** and closes those waters to shellfishing when the concentration reaches a critical level. In addition, some areas can be closed for administrative reasons such as the absence of a monitoring program and/or the potential for contamination. For example, the low salinity areas of upper Chesapeake Bay are not very productive shellfish grounds; therefore, it is not cost-effective to monitor these waters for coliform bacteria and, hence, they are closed to shellfishing. Also, several coastal bays are closed to shellfishing because of the potential for contamination from a variety of sources.



Oyster harvest in the Chesapeake Bay

Photo by: Chesapeake Bay Program

Shellfishing is prohibited in 3% of the 3,660,000 acres classified as potentially productive shellfish ground. Shellfishing is restricted (shellfish can be harvested but must be brought to another location to ***depurate*** prior to consumption) in an additional 179,000 acres (5% of the area). Approximately 67,000 acres (2%) are conditionally closed, such as after rainfall events that may wash contaminants into the estuary. The breakdown by major estuary is shown in Figure 20. Figure 21 shows the locations of closures. Considering the degree of urbanization in the Mid-Atlantic Region, it is encouraging that the relative acreage of closed waters is low, and it has decreased from 18% in 1985 and 1990 to 10% in 1995.

Filter Feeding

Bivalve shellfish are filter feeders, meaning they pump water through their gills for both respiration and feeding. As they pump this water, the gills filter out particulates, removing suspended material from the water. Because shellfish are such effective filters of the water, they tend to accumulate whatever pollutants are in the water. This can result in the closing of an area to shellfishing due to their contamination. Most frequently, this is due to bacterial contamination from a multitude of possible sources.

Of the total acreage in Chesapeake Bay that is harvest-limited (conditional, restricted, or prohibited), the most common sources of contamination are marinas, urban runoff, upstream sources carried down the tributaries, or unidentified sources (Figure 21). This figure also illustrates the relative magnitude of the effects of the major sources on harvest-limited acreage. Any given system may be impacted by more than a single source, complicating remediation efforts. The major contributors in the Delaware Estuary are sewage treatment plants and leaking septic systems. Because of the wide diversity of land uses on the Delmarva Peninsula, there are no dominant sources of contamination.

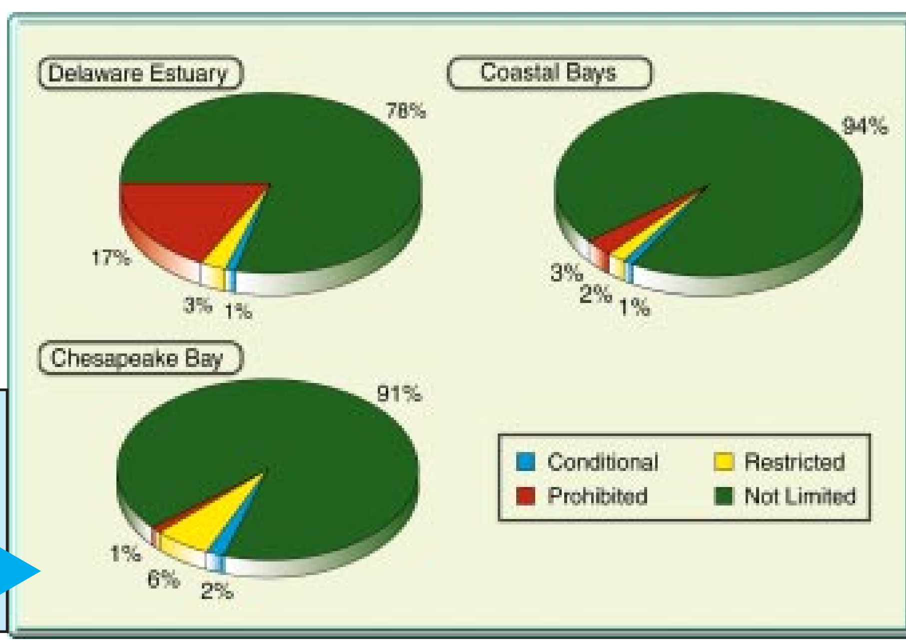


Figure 20. Shellfish closures in Mid-Atlantic estuaries expressed as a percent of acreage classified as *productive* grounds. (See text for definitions)

Source: NOAA, 1997

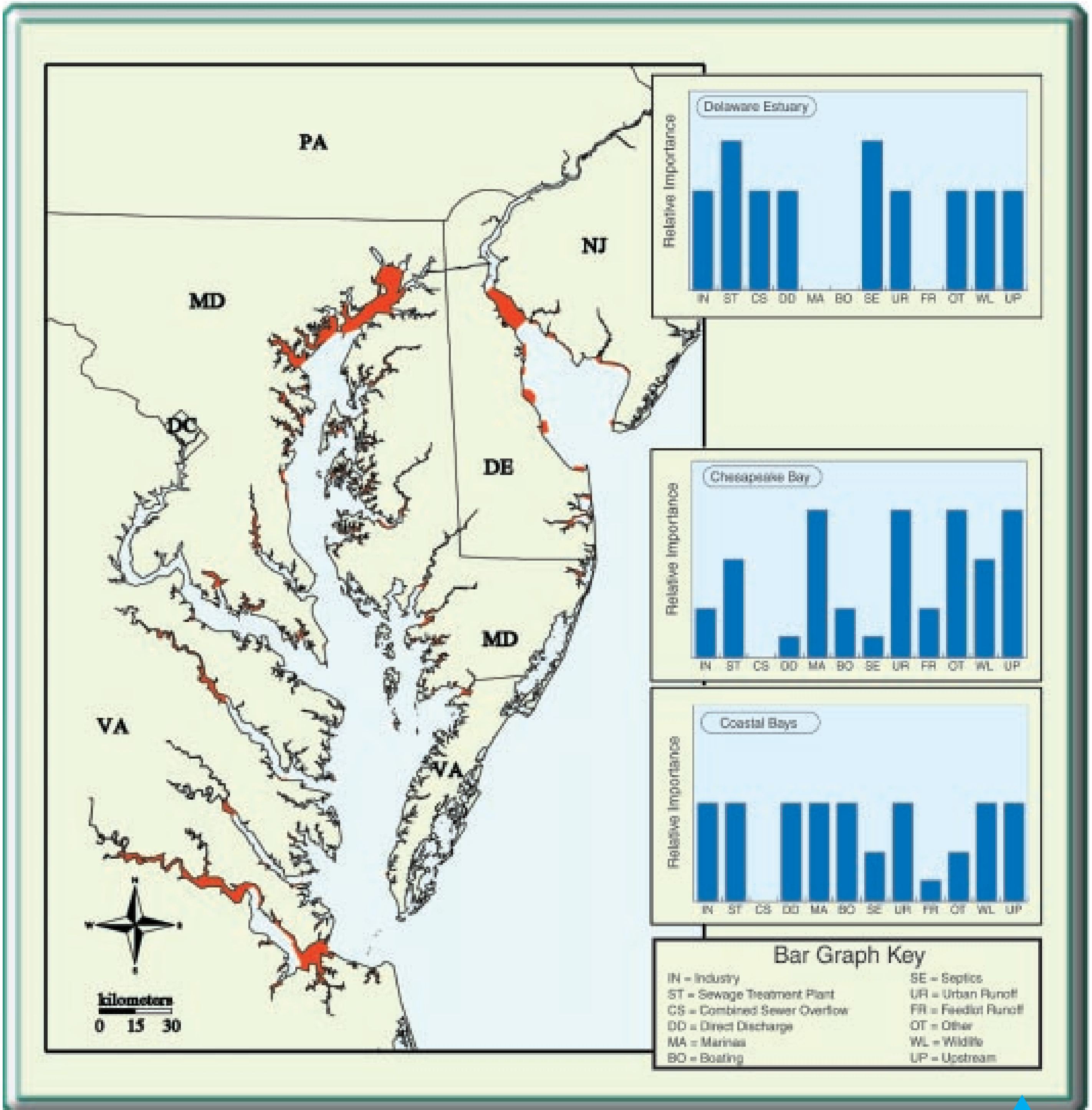


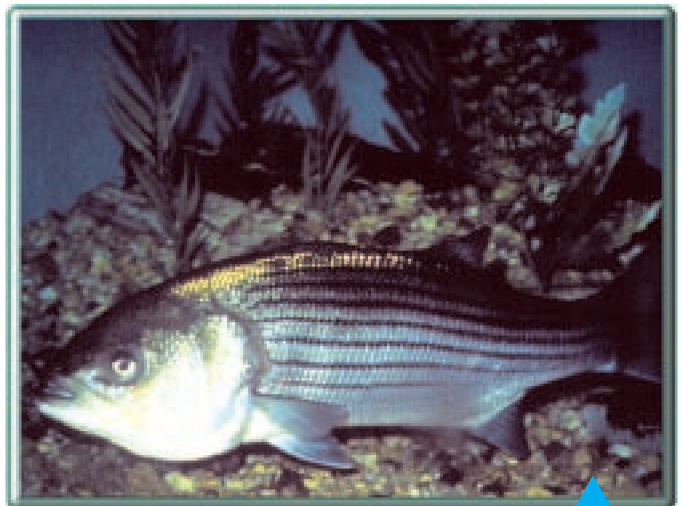
Figure 21. Shellfish closure areas (in red) and bar graphs showing relative importance of major sources of contamination. Many closure areas are too small to show up on this map.
Sources: State closure records; NOAA, 1997

Fish Stock Assessment

Fish generally occupy higher ***trophic levels*** in the marine environment, and their abundance, distribution, and condition are considered indicators of ecosystem health. Many factors cause changes in fish abundance and species composition. Among them are nutrient concentrations, turbidity from suspended sediment, phytoplankton abundance, salinity, current velocity, overfishing, wetland loss, weather and oceanic conditions, and predator abundances. Fish are mobile and able to detect and react to changing environmental conditions. Tolerant fish remain in degraded coastal systems, whereas more sensitive species move to more habitable regions or simply succumb to the stress. Abundant juvenile fish and diversity in species indicate that a system provides sufficient habitat to support reproduction and growth. Juvenile fish are sensitive to anthropogenic stresses and, therefore, their abundance may indicate how much contamination exists in a system. Because higher trophic levels in estuarine systems require a rich diversity of intact ecosystem functions to survive, grow, and reproduce, fish abundance and species richness can be a broad and useful indicator of estuarine health.

Summary of Fish Trends Data

- The striped bass fishery in Chesapeake Bay and the Delaware Estuary is considered to be recovering.
- American shad populations are improving region-wide.
- The white perch population is stable but low in Chesapeake Bay.
- Summer flounder populations are stable or perhaps declining in the Delaware Estuary.
- Summer flounder populations are improving in the Maryland coastal bays.
- Drum species populations are variable in the Delaware Estuary.
- Shore-zone species composition suggest degraded conditions in the Delaware coastal bays.
- Shore-zone species compositions suggest generally healthy conditions with slight indications of degradation in the northern coastal bays of Maryland.



Striped Bass

Photo by: U.S. Fish and Wildlife Service

The Mid-Atlantic Region is a diverse area containing many different types of habitat suitable for fish. This variety of habitats, along with the complexity of fish community interactions and the migratory nature of many species makes it extremely difficult to assess the overall condition of the fish community in an estuary. In addition, different types of indices are used to assess trends in different fish populations. Because of these problems, this section focuses on specific, commercially important species rather than the fish community as a whole. Generally, fish monitoring in the region is based on a combination of trawl sampling and ***seine surveys***. In addition, commercial fish landings data are available and were used for this report.

Striped Bass (*Morone saxatilis*)

The striped bass (or rock fish) is an important commercial and game fish for the Mid-Atlantic Region. It is an ***anadromous fish*** that uses freshwater environments such as the upper Chesapeake Bay and the Hudson, Roanoke, and Delaware Rivers for ***spawning***. Adult striped bass use feeding areas in the Delaware Estuary, Chesapeake Bay, and along the Atlantic Coast northward to Maine. Striped bass were plentiful before the industrial revolution, and population reductions were apparent by the early 1900s. This species has undergone significant scrutiny since the decline of stocks in the 1930s. Factors involved in these declines include both overfishing and pollution. Moreover, habitat degradation and losses from stress such as low dissolved oxygen in bottom waters of coastal embayments have been associated with the lowered populations. Researchers have attributed recovery throughout the

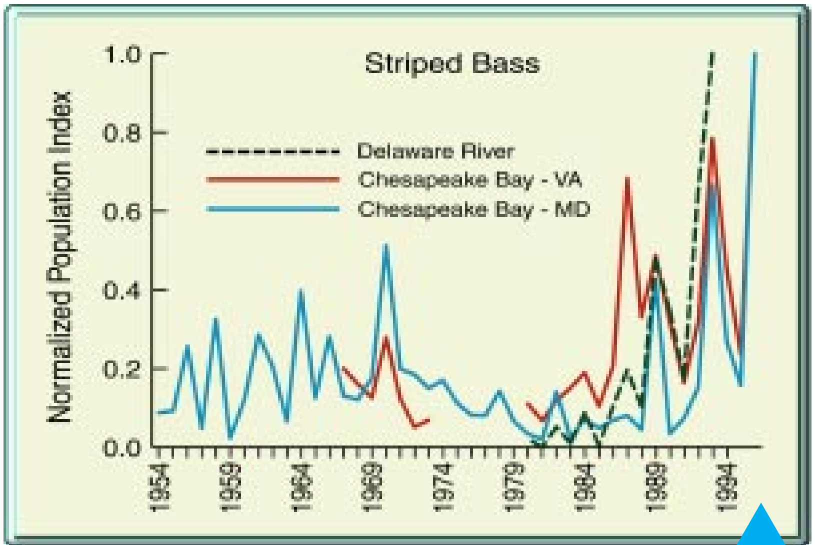


Figure 22. Normalized indices for juvenile striped bass indicating recent improvements to juvenile fish stocks. For the Delaware River it represents the seine index; for Chesapeake Bay it represents the juvenile index for VA and MD. Numerical comparisons between systems cannot be made due to the differences in the indices.

Source: NOAA; Chesapeake Bay Office; Dove and Nyman, 1995.

1980s to improved water quality as well as reduced fishing pressure. Water quality improvements were primarily due to upgraded sewage treatment. Overfishing was halted by protective management practices implemented by the states, including a fishing moratorium from 1985-1990 in Chesapeake Bay and the Delaware Estuary. Since that time, population levels have improved (Figure 22). Because of the improved conditions, the Atlantic States Marine Fisheries Commission declared the fish stock restored, and fishing restrictions on the striped bass have been liberalized (but still exist). The 1996 data in the Chesapeake Bay show a record juvenile population index in both Virginia and Maryland, exceeding the previous record set in 1993.

American Shad (*Alosa sapidissima*)

The situation for the American shad is quite different from that of the striped bass. Another anadromous fish, the American shad migrates annually into freshwater areas of the Delaware Estuary and Chesapeake Bay. Since its high mark in the late 1800s, a precipitous drop in commercial landings has been seen in both systems due to excessive harvesting, pollution, and construction of dams and other waterway obstructions causing loss of spawning grounds (Figure 23). Over the past few years, region-wide abundances have improved dramatically as a result of federal, state, and interstate efforts to reduce fishing pressure, increase spawning ground accessibility, and improve water quality by improving wastewater treatment (Figure 23 insert). However, this species remains under strict management.

White Perch (*Morone americana*)

The white perch, an important commercial and sport fish in the Delaware Estuary and Chesapeake Bay, has shown a relatively stable population over the past 100 years. In Chesapeake Bay, fluctuations in the Maryland juvenile index were greatest in the late 1960s through the 1970s and decreased throughout the 1980s. The index jumped markedly in 1993 to its highest level—more than four times the average over the survey period. Thus, some consider the white perch to be an under-used resource. Several factors are considered important in its ability to maintain a stable population, including its ***fecundity***, early maturation, expansive spawning and nursery grounds, and tolerance of poor water quality.

Summer Flounder (*Paralichthys dentatus*)

The summer flounder is a popular sport and commercial fish in the Mid-Atlantic Region. It ranges from Canada

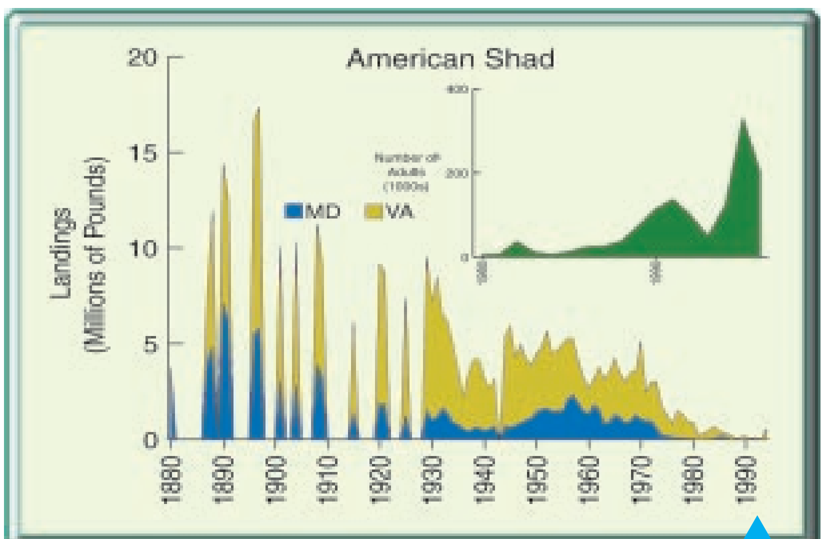


Figure 23. American shad landings in Chesapeake Bay showing decreased commercial landings since the late 1800s. Gaps in the late 1800s and early 1900s do not represent zeros, but rather missing data. 1993-94 data are preliminary. Recent data on the abudance of adult fish in the upper Chesapeake Bay (insert) show improvement of stocks.

Source: NOAA; Chesapeake Bay Office; Chesapeake Bay Program 1997.

to Florida and is a migratory resident of coastal estuaries during the summer, moving offshore to the ***continental shelf*** in the winter. The summer flounder is heavily exploited and has been managed by federal and state regulations during the 1990s. Despite high fishing pressure, the summer flounder persists in the Delaware Estuary. In the Maryland coastal bays, summer flounder showed a peak in abundance in the early to mid-1980s followed by a decrease in the late 1980s. A gradual improvement in the population during the 1990s has been documented.

Drum species

Many species within the drum family are important recreational and commercial fish and significant contributors to the food web due to their abundance and range. In the Delaware Estuary and Maryland coastal bays, four species of drum are significant—spot (*Leiostomus xanthurus*), black drum (*Pogonias cromis*), Atlantic croaker (*Micropogonias undulatus*), and weakfish (*Cynoscion regalis*). Significant historical variations in ***young-of-the-year*** abundances and annual commercial landings of spot, black drum, and Atlantic croaker are thought to be due to many factors. These include summer wind regimes, winter temperature, environmental variations in spawning grounds, and effects of juvenile predators such as jellyfish. The most recent data for Atlantic croaker and weakfish show improved ***recruitment***. For example, above average recruitment for Atlantic croaker in the Maryland coastal bays was observed from 1993 to 1995; however, it was still much lower than the recruitment observed in 1974. The Delaware Estuary showed nearly a 10-fold increase in 1992 compared with the 1980s. Finally, the 1995 trawl catch for weakfish was the second largest catch between 1972 to 1995.

Shore-Zone Species

Historical data on shore-zone species (those that inhabit shore-zone habitats and shallow water environments) have been studied to evaluate changes in species composition in response to changes in environmental stress. In the Delaware coastal bays, significant physical, chemical, and habitat changes have occurred over the last 60 years, including increased levels of chlorophyll, suspended solids, nutrients, and salinity. These changes have resulted in shifts in species composition. For example, in the White Creek area of the Delaware Estuary, species have shifted from juvenile menhaden, tidewater silversides, and bay anchovy to killifish and mummichog. Overall, pollution-tolerant species such as cyprinodontids (e.g., killifish) are becoming more dominant as sensitive species decrease (Figure 24). These changes are consistent with the hypothesis that more sensitive fish have left the areas and more tolerant species have taken their place. In the Maryland coastal bays, fish community diversity has remained relatively stable; however, in some northern areas, pollution tolerant species have increased in abundance. Future environmental alterations could result in a more significant shift, as has occurred in the Delaware coastal bays.

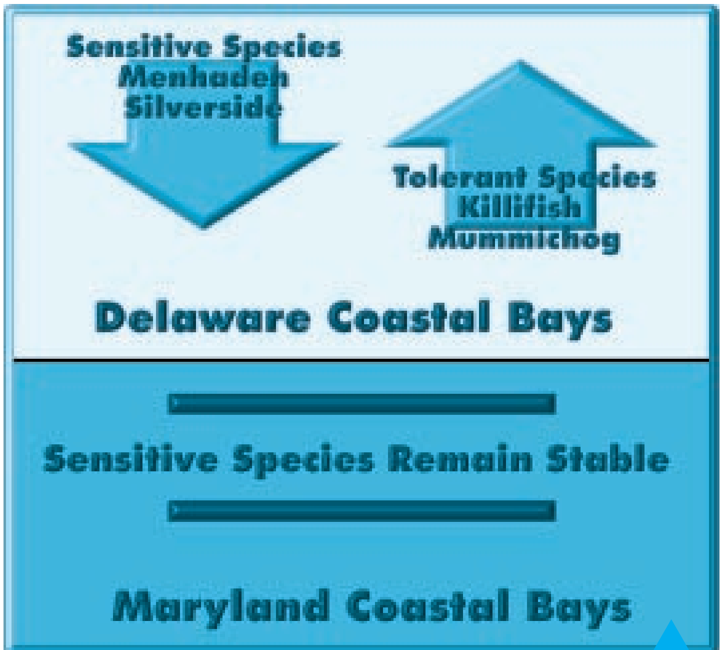


Figure 24. Schematic depiction of the changes in the Delaware and Maryland coastal bays' shallow water fish species over the past 20-30 years. Note changes from sensitive species to more tolerant species in the Delaware coastal bays compared to the stability in the species composition in the Maryland coastal bays.

Source: Chaillou et al., 1996

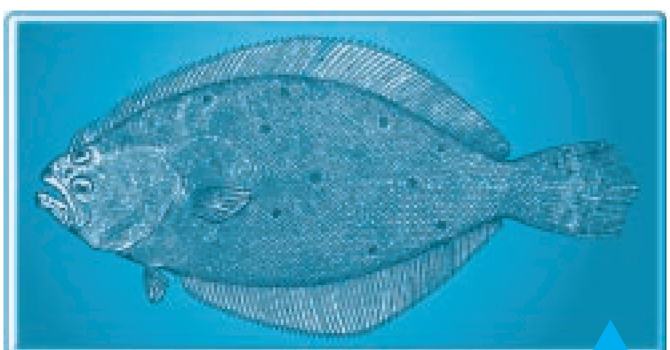


Illustration of Summer Flounder

Contaminants in Fish and Shellfish

Chemical contaminants may enter a marine organism in several ways—direct uptake from contaminated water, consumption of contaminated sediment, or consumption of previously contaminated organisms. Once an organism is contaminated, it tends to retain (***bioaccumulate***) these chemicals unless there is an effective cleansing mechanism. Chemical concentrations may increase with subsequent feedings. An organism higher on the food chain may "inherit" the levels of chemicals present in the organisms lower in the chain. This process, known as ***biomagnification***, leads to an increase of chemical contaminants, perhaps to toxic levels. All organisms that consume contaminated organisms, including humans, may be at risk of suffering some toxic effect. The accumulation of these contaminants also may result in increased susceptibility to disease or effects on growth or reproduction. It should be noted that some chemical contaminants are not bioaccumulated or biomagnified.

Contaminant levels in fish and shellfish from the Delaware Estuary, Chesapeake Bay, and the Delmarva coastal bays vary widely. Some of the lowest fish or shellfish contaminant levels in the nation have been found in the Mid-Atlantic Region. At the same time, fish or shellfish from other sites in the region have ***tissue residues*** that are among the highest in the nation. Many contaminants generally are at or below the national average, and the levels in both fish and shellfish appear to be declining. Generally, tissue residues are higher in samples from the Delaware Estuary than in samples from Chesapeake Bay, while levels in the upper Chesapeake are higher than in the lower Chesapeake Bay. The ban on the use of certain chemicals (*e.g.,* Chlordane, Kepone, PCBs, DDT) apparently has led to gradual, though significant, declines in the concentrations of these chemicals in fish and shellfish. In some cases (*e.g.,* Kepone in the lower James River) tissue residues have dropped below action or ***advisory levels***, resulting in the lifting or downgrading of bans on consumption. Concentrations of a few heavy metals in fish and shellfish may, however, be increasing in some localized areas. Samples taken from urban watersheds (*e.g.,* Patapsco River near Baltimore Harbor, the Potomac River near Washington, D.C., the James and Elizabeth Rivers near Norfolk) generally have elevated concentrations of multiple contaminants, typical of anthropogenic input.

Contaminant Levels in Fish

Although concentrations of many contaminants are low or not detected in fish in the Mid-Atlantic Region, several ***hot spots*** exist. ***Fish consumption*** bans or advisories exist in many of these areas (Figure 25). In Delaware, ***bans*** or advisories on consumption of fish due to elevated PCB concentrations are in effect for the tidal portions of the Red Clay, Christina, Brandywine, and Delaware Rivers, as well as Little Mill Creek, White Clay Creek, and Delaware Bay. Chlordane levels that exceed the FDA action level have been reported in the upper Delaware Estuary. High Chlordane concentrations have resulted in consumption advisories for several fish species in the

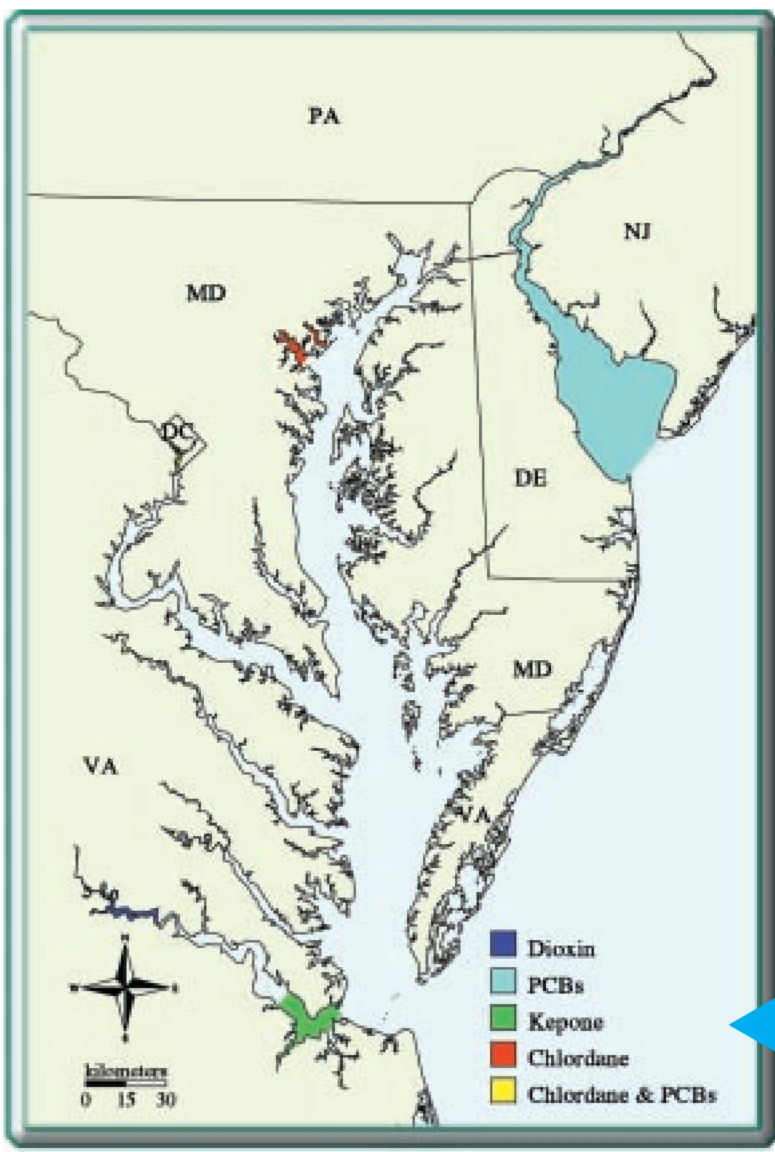


Figure 25. Fish consumption bans or advisories in effect for Delaware Estuary, Chesapeake Bay, and Delmarva coastal bays.

Sources: DNREC, 1994, 1996; Chesapeake Bay Program, 1993; Delaware Estuary Program, 1996

Back River and Baltimore Harbor, Maryland. Chlordane and PCB levels in the Anacostia and Potomac Rivers in the District of Columbia have prompted advisories, while kepone levels, although decreasing, have resulted in an advisory on the consumption of fish from the lower James River in Virginia.

Contaminant Levels in Shellfish

Tissue residue data from shellfish collected throughout the region are difficult to characterize. Some of the lowest tissue residues measured in shellfish in nationwide studies have been found in the Delaware Estuary, Chesapeake Bay, and the Delmarva coastal bays. Other contaminant levels are among the highest recorded. Figure 26 compares shellfish tissue residues from the region to national averages. Silver concentrations in oysters from the region range from the lowest nationwide to within the highest 12 percent nationwide. Copper, cadmium, and zinc levels in bivalves are among the highest measured in the nation, including the highest measurements for zinc and cadmium. Mercury tissue residues from Chesapeake Bay are low, accounting for many of the lowest levels in the nation. Some of the lowest chromium tissue residues were found in the Mid-Atlantic estuaries, but four locations had high levels. Similarly, lead levels ranged from very low to one site with a high concentration. DDT and related compounds, Chlordane and related compounds, and PCB concentrations tended to be higher than the national average at most of the sampled sites in the Mid-Atlantic Region, with multiple sites rated high. PAH concentrations in the region also range from the lowest in the nation to one site classified as high. In general, more of the contaminants were classified as having high concentrations in the Delaware Estuary than in Chesapeake Bay and the coastal bays. The extremes in the concentrations probably indicate the presence of hot spots associated with urban activities surrounded by more pristine conditions.

Relatively few areas in the region have bans or advisories on the consumption of shellfish. In Virginia, high levels of PAHs and their metabolic breakdown products have led to bans on the consumption and collection of oysters and crabs in the Elizabeth River and Little Creek. Similarly, shellfish collection and consumption is prohibited in the Lafayette River. PCB levels in blue crabs have resulted in consumption advisories for portions of the Delaware Estuary. In general, however, shellfish contaminant levels are relatively low throughout the Region.

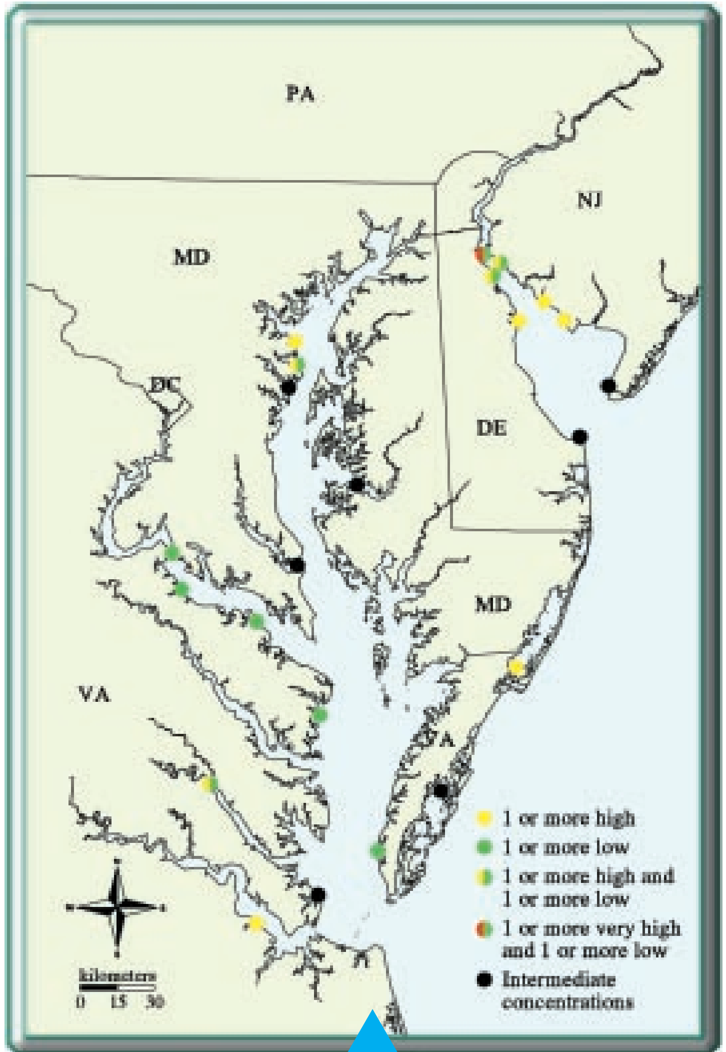


Figure 26. Shellfish tissue residues compared to national averages. "High" indicates concentrations that are significantly above the national average; "low" means significantly below the national average. This illustrates the range of concentrations encountered in the Region.

Source: NOAA, 1994

Incidence of Disease

Probably the most disturbing sign of pollution to the angler is catching a fish with some form of external abnormality. However, to the untrained observer, this is a poor indicator of degraded water quality. What the angler believes is fin rot or an open ulcer might actually be an injury. Athough the cause of an abnormality may not be chemical contamination, a high incidence of such conditions would indicate an environmental problem.

EPA's Environmental Monitoring and Assessment Program (***EMAP***) conducted an examination of fish for external abnormalities in its 1990-1993 survey of the Mid-Atlantic estuaries. A total of 13,467 fish from 177 stations (138 in the Chesapeake system, 32 in the Delaware Estuary, and seven in the Delmarva coastal bays) were examined by trained personnel. Only 41 fish, or three per thousand (0.3%) examined, were afflicted with fin erosion, ulcers, growths, or abnormal lumps (Figure 27). The majority of these fish were of bottom-dwelling species such as channel or white catfish, or brown bullhead. No affected fish were collected in the Delmarva coastal bays. At 13 of the 20 stations where fish with a ***pathological condition*** were found, only a single fish with an abnormal condition was collected per station. The station with the highest incidence was located in Maryland's Back River. The low incidence of pathologies found in the Mid-Atlantic is comparable to the overall incidence determined for the east coast from Cape Cod, Massachusetts, to the mouth of the Chesapeake. The incidence rate is only slightly higher than the 0.2% determined for the South-Atlantic coast. It is considerably lower than the 1% determined by EMAP for the estuaries of the Gulf of Mexico.

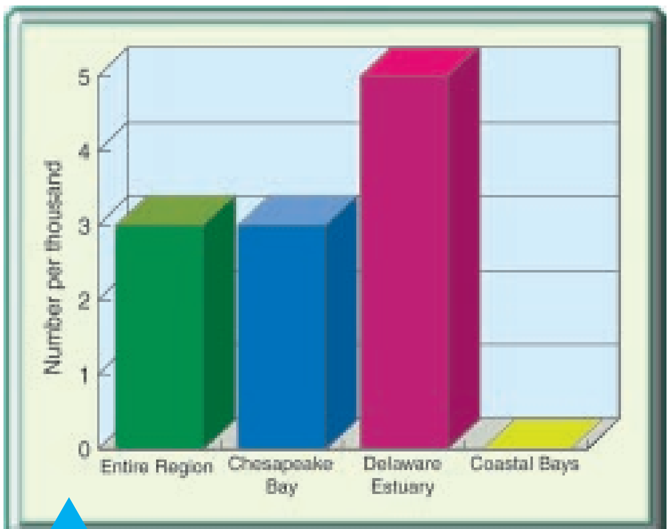


Figure 27. Incidence of pathological condition in fish of Mid-Atlantic estuaries.

Source: U.S. EPA, EMAP Database (1990-1993)

Although over fishing and environmental factors may have contributed to the depletion of oyster stocks, disease generally is recognized as the major cause of the decline over the past few decades. The two main diseases affecting oysters are ***Dermo*** and ***MSX***, caused by the protozoan parasites *Perkinsus marinus* and *Haplosporidium nelsoni,* respectively. Dermo was discovered affecting oysters in Chesapeake Bay waters in the 1950s and the Delaware Estuary in 1990. Although Dermo was first introduced to the Delaware Estuary in the 1950s with imports of seed oysters from the Chesapeake, it failed to become established at that time. MSX was first observed in Chesapeake Bay in 1959 and in the Delaware Estuary in 1957. These two diseases have decimated the oyster populations of both estuaries. Both parasites are most active in waters with salinities between 15 ppt and 30 ppt, which is why the most productive oyster beds today are in lower salinity areas, such as the middle James River. Most of the waters of the Mid-Atlantic estuaries fall within this mid-salinity range (Figure 6), resulting in an extremely widespread problem. The ***spatial extent*** of these diseases has varied over the past decades with climatic conditions (*e.g.*, amount of rainfall and summer temperatures). The mid-1980s were unusually dry and warm years in the Mid-Atlantic states, which resulted in the intrusion of more saline waters further up into the estuaries than usual. This intrusion introduced the diseases to oyster beds throughout the bays and resulted in mass mortalities. More than 75% of all oysters in Chesapeake Bay were killed, and the stock has not recovered. Both diseases are present in the Delmarva coastal bays, but are not as ***virulent*** in the higher salinity seawater. Although some oysters in the Delmarva coastal bays have been affected, large-scale kills like those in the Chesapeake Bay and the Delaware Estuary have not occurred. However, significant reductions in oyster populations have occurred in other coastal systems.

Disease Issues

There are three major disease issues of ecological and economic importance in the Mid-Atlantic estuaries: pathological conditions in fish, oyster disease, and fish kills due to bacterial infection. The incidence of pathological conditions in fish and fish kills due to disease is low in Mid-Atlantic estuaries. Unfortunately, the prevalence of oyster disease is high and has nearly destroyed the oyster fishery.

One question frequently asked is why have the oysters become infected. One popular theory is that stress from pollution reduced the oyster's resistence to disease. Researchers have shown that pollutant stress increases the oyster's susceptibility to disease. Although there is no known way to combat the disease directly, researchers are currently studying the feasibility of introducing disease-resistant strains of oyster or other species of oysters to local waters to reclaim the fishery. It is important to note that these diseases pose no known human health threat, either through contact with seawater or the ingestion of contaminated shellfish.

Another highly visible indicator of environmental degradation is the incidence of fish kills. Fish kills can result from a number of both natural and anthropogenic causes. The majority of fish kills are probably a result of low dissolved oxygen (hypoxia) in the water due to high water temperatures, over-enrichment (eutrophication), or simply the movement of too many fish into an embayment (the fish use up the oxygen as they breath). Other potential causes of fish kills include fishing by-catch, chemical pollution, toxic algae, and disease. The massive kills of millions of menhaden in upper Chesapeake Bay in the late 1980s was attributed to a *Streptococcus* infection combined with high water temperatures (resulting in hypoxia). We have not seen such conditions in the 1990s. NOAA reported that the highest number of fish kills in the Mid-Atlantic Region in the 1980s occurred in Maryland's Anne Arundel and Baltimore Counties. Most of these fish kills were attributed to disease and low dissolved oxygen due to a combination of over-enrichment and large numbers of fish entering relatively small embayments. This trend has continued into the 1990s with the same portion of Chesapeake Bay exhibiting the highest incidence of fish mortalities. However, disease has played a less important role.

During the summer of 1997, a number of fish kills occurred in several of the small tributaries of Chesapeake Bay and some of the coastal bays. The causative agent for these kills was determined to be the toxic dinoflagellate *Pfiesteria piscicida* or *Pfiesteria*-like organisms. This complex organism can reside as a cyst in the sediments of estuaries or as a non-toxic dinoflagellate. These cysts can turn into toxin-producing cells when conditions are right (warm water, high nutrient loads, moderate salinity, poor flushing) and they

Pfiesteria

- *Pfiesteria* is not a "disease" but a dinoflagellate.
- Dinoflagellates are unusual organisms, part plant and part animal.
- Dinoflagellates are a normal component of the marine ecosystem.
- *Pfiesteria* has 24 different life stages, including bottom-dwelling cysts and toxic stages.
- Most outbreaks occur in warm water and at a salinity of about 15 ppt.
- The organism occurs naturally from the Gulf of Mexico to the Delaware Estuary.
- A large number of research projects are currently underway to better understand this organism.

Fish exhibiting sores caused by *Pfiesteria*.

Photo by: Maryland Department of Natural Resources

detect large numbers of fish. These cells release a powerful neurotoxin that stuns the fish. Fish then develop sores and begin to die. These kills can last a few hours or several days. Usually by the time the kill has been noticed, the organism has reverted back to cysts and has settled back into the sediment. Within a day or so, the toxin in the water has degraded, leaving no signs of the organism.

Waterfowl

Another important living resource of Mid-Atlantic estuaries is waterfowl (*e.g.,* ducks, geese, swans) and other birds associated with the water (*e.g.*, herons, egrets, osprey, eagles). Birds not only play a major ecological role in these systems, but also provide a recreational opportunity for hunters, photographers, and bird watchers. Many species are highly dependent upon wetlands and submerged aquatic vegetation for their survival, and alterations to these environments affect the populations of resident and migratory birds. Today, habitat alteration is probably the major factor controlling *local* bird populations. We stress "local" because many of the species found in the estuaries of the Mid-Atlantic are migratory, meaning they spend only a part of the year in this area. As such, their overall abundance may be determined by environmental factors where these birds summer and breed, such as the Prairie Pothole wetlands of the north-central United States and plains of Canada. This makes the "bird story" a particularly complicated one. For example, green-winged teal (*Anas crecca*) are at their highest levels since the 1950s, not because of conditions in the Mid-Atlantic, but because conditions in the Prairie Pothole region have been favorable over the past several years. Significant rain has resulted in the emergence of many ponds that had dried up during 30 years of drought.

One interesting ecological story playing out in Chesapeake Bay is the competition between the black duck (*Anas rubripes*) and the mallard (*Anas platyrhynchos*). Whereas mallard populations are on the rise, black ducks are decreasing (Figure 28). This is largely due to habitat loss and the release of mallards to the Bay. Valuable black duck habitat is lost as wetlands are eroded and land is developed for human use. Black ducks tend to stay away from people, and will abandon wetlands in close proximity to human development. Mallards, on the other hand, are more adaptable to the presence of people and are more likely to be found in developed areas. Also, over the past several decades mallards have been released to the Bay to increase populations for hunting. The effect of this on the black duck population is unknown, but both species are in competition for the same resources. Further complicating this story is the fact that these two species can interbreed, resulting in ***hybrids***. The picture is different for the coastal bays (Figure 28) and the Delaware Estuary, where black ducks outnumber mallards and both populations are stable.

Another species of migratory waterfowl that is now a resident of Mid-Atlantic waters is the Canada goose (*Branta canadensis*). Although geese have always wintered in the Mid-Atlantic, they did not become permanent residents until the early 1900s when some were brought to Chesapeake Bay from the Great Basin population to be used as live decoys. This practice ended in the 1920s, but the birds remained and bred, with some taking up residence in the Delaware Estuary as well. The largest populations of resident geese are

Mallard Ducks

Photo by: U.S. Fish and Wildlife Service

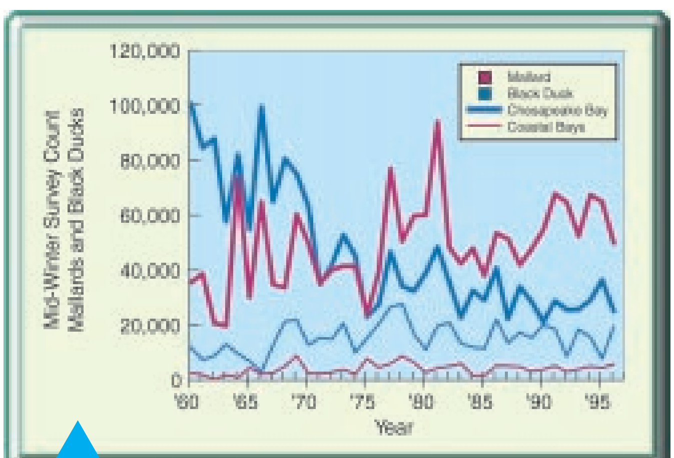
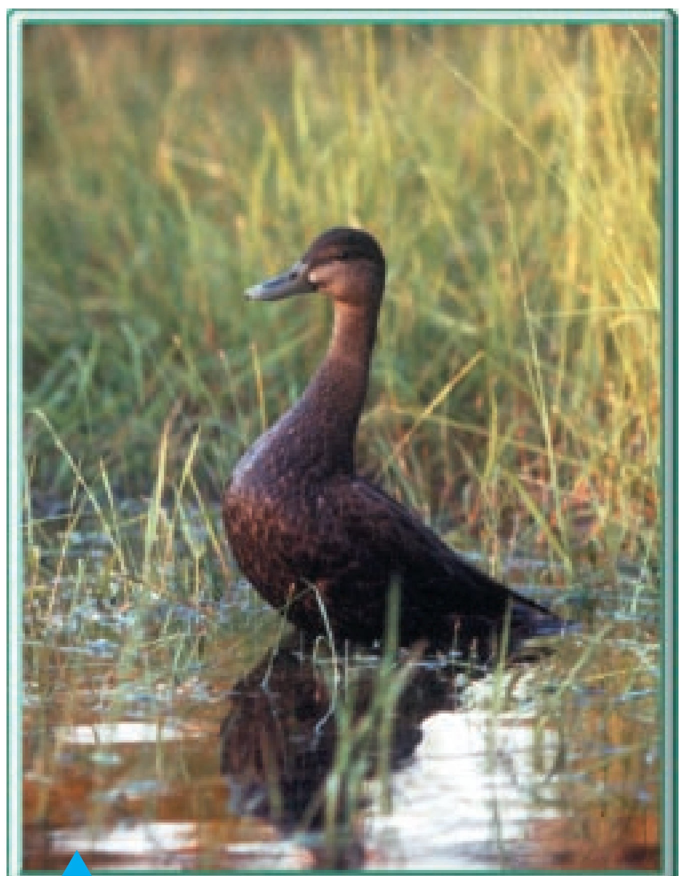


Figure 28 . Trends for mallards and black ducks in Chesapeake Bay (heavy lines) and the Delmarva coastal bays (thin lines). The Delaware Estuary has been excluded for the purpose of clarity. The graph shows the mid-winter survey count, not an actual population count.

Sources: U.S. Fish and Wildlife Service, Mid-Winter Migratory Bird Survey



Black Duck

Photo by: Wayne Munns

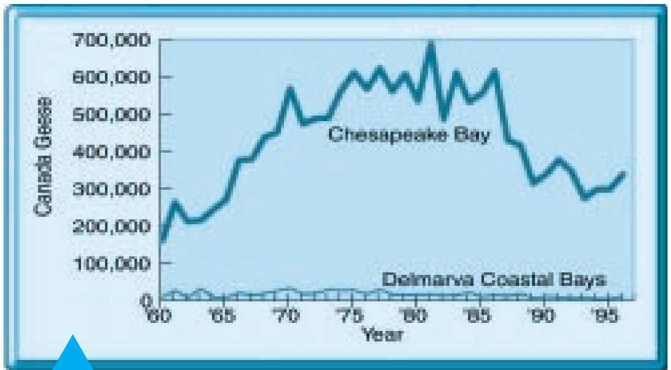


Figure 29. Trends for Canada geese in Chesapeake Bay and the Delmarva Coastal Bays. The Delaware Estuary has been excluded for the purpose of clarity, but the trend is similar to that of the coastal bays. The graph shows the mid-winter survey count, not an actual population count.

Sources: U.S. Fish and Wildlife Service, Mid-Winter Migratory Bird Survey

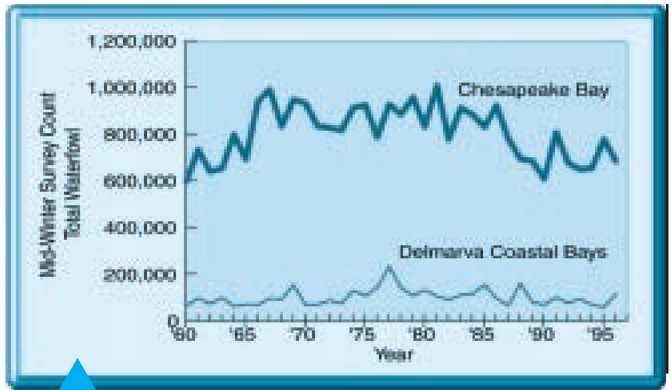
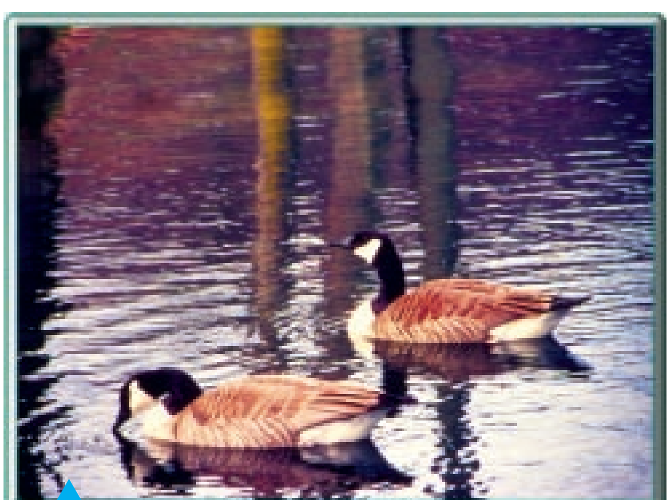


Figure 30. Overall trend for all waterfowl in Chesapeake Bay and the Delmarva coastal bays. The graph shows the mid-winter survey count, not an actual population count.

Sources: U.S. Fish and Wildlife Service, Mid-Winter Migratory Bird Survey

found on the western side of Chesapeake Bay. Because this area is more densely populated by man, most of the hunting occurs on the more remote eastern shore. Most of the geese along the eastern shore are migrants, and because of overharvesting and weather patterns to the north, the population of migrant geese has declined sharply. However, these populations are beginning to recover (Figure 29). Therefore, despite an overall abundance of Canada geese in the Chesapeake Bay basin, hunting has been restricted to early September to ensure that only resident geese are taken and to allow migrant populations to recover.

Other species of waterbirds with increasing populations include the diving ducks (canvasbacks have reached the restoration goal for Chesapeake Bay) and the great blue heron (a colonial nesting bird). Figure 30 shows the trend in the mid-winter survey count for all waterfowl in Chesapeake Bay and the Delmarva coastal bays. It shows how variable counts can be from year to year. This variability can be due to a number of conditions, both natural and man-induced. Although there has been no significant overall trend for waterfowl as a group, some species have increased while others have decreased. Scientists are concerned that local populations of some species have not increased over the past few years. Wet conditions in the Prairie Pothole region of the country has led to a significant increase in the overall national population of many migratory species. A similar increase has not followed in the Mid-Atlantic because the birds are favoring other wintering sites, such as along the Gulf Coast. One popular theory among scientists is that the increase in human activity along Mid-Atlantic coast, coupled with the loss of SAV and wetlands, is making this region less "attractive" to many species of migratory waterfowl. One question being asked is what will happen to the Mid-Atlantic migratory waterfowl populations if prolonged drought conditions return to the Prairie Potholes.



Canada Geese

Photo by: U.S. Fish and Wildlife Service

Threatened and Endangered Species

Species of plants or animals can become ***threatened*** or ***endangered*** due to habitat loss, unregulated killing or collection, pollution, disease, predation, or competition with other species. Although a species may become

extinct for “natural” reasons such as being out-competed by another species, over the past century the rate at which species are becoming endangered has significantly increased due to man’s activities. In many areas of the United States, rapid growth in population, industry, and agriculture has led to significant stresses on a range of native species of plants and animals. Recognizing the impacts of these stressors, Congress took action in 1973 by passing the Endangered Species Act, “making the conservation of endangered and threatened species and the ecosystems that sustain them a National priority and instituting public policy to work for their recovery.”

The Mid-Atlantic Region has experienced some of the most rapid population growth, industrial development, and intensive agriculture in the country. Not surprisingly, many organisms relying on the estuaries of the Mid-Atlantic have suffered. Over 50 species of plants and animals are listed as threatened or endangered in the Mid-Atlantic states. Although most are not associated directly with estuaries, several are. These include the bald eagle, peregrine falcon, piping plover, several species of sea turtles, and shortnose sturgeon. New Jersey, Delaware, Maryland, and Virginia have made formal declarations to protect threatened and endangered species. For example, “it is in the best interest of the state to preserve and enhance the diversity and abundance of nongame fish and wildlife and to protect the habitat and natural areas harboring rare and vanishing species of fish, wildlife, plants, and areas of unusual scientific significance or unusual importance to the survival of Delaware’s native fish, wildlife and plants in their natural environments.” These efforts have reversed the process of extinction for most of the species we associate with the estuaries (Figure 31). Continued efforts to protect these sensitive organisms hopefully will result in their populations reaching levels sufficient to ensure their continued existence.

Figure 31. Trends in selected threatened and endangered species in the Mid-Atlantic estuaries. Up arrow indicates improving trend, question mark indicates trend is uncertain. None of the major estuarine threatened or endangered species currently are declining.

Source: U.S. FWS Endangered Species Database

Bald Eagle

Photo by: U.S. Fish and Wildlife Service

Profiles of Selected Endangered Species

Bald eagle (*Haliaeetus leucocephalus*)

This species formerly nested throughout North America. Population declines were attributed to habitat loss, illegal shooting, and the effects of DDT on reproductive success. The eagle has benefited from increased regulation of pesticides, nest site protection, aggressive habitat management, and reintroductions. Many states have successfully reestablished nesting populations by translocating young birds from areas with healthy populations to suitable, unoccupied habitat. Public awareness campaigns and vigorous law enforcement have helped reduce illegal shooting of eagles. Bald eagle numbers in the lower 48 states have increased from approximately 417 nesting pairs in 1963 to more than 4,000 pairs in 1993. In addition, there are an estimated 5,000 to 6,000 juvenile bald eagles in the lower 48 states. As a result of the significant progress toward recovery, the species has been reclassified from endangered to threatened in the lower 48 States. The bald eagle is an example of success in the recovery of an endangered species and is the result of more than twenty years of national effort to change the trend in population decline. A wide range of actions were taken to conserve and restore habitat and control pesticide contamination problems.

Shortnose Sturgeon

Photo by: U.S. Fish and Wildlife Service

Kemp's ridley turtle (*Lepidochelys kempii*)

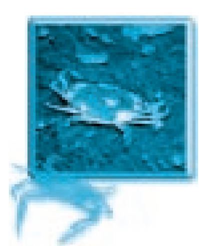
There are only seven living species of sea turtles in the world and the Kemp's ridley is under the greatest threat of extinction. Virtually the entire world population nests annually in a single locality on a beach near Rancho Nuevo, Mexico. When this nesting site was first discovered in 1947, the adult female population was estimated to be greater than 40,000 but has decreased to approximately 490 based on recent estimates. Juvenile turtles are thought to be carried north via passive transport in the Gulf Stream, where they feed

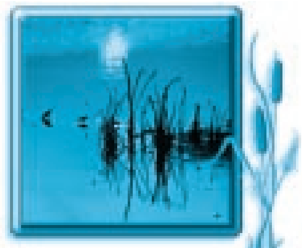
Kemp's ridley turtle

Photo by: U.S. Fish and Wildlife Service

Shortnose sturgeon (*Acipenser brevirostrum*)

The shortnose sturgeon is the smallest of the three sturgeon species in eastern North America. It is an anadromous fish that spawns in coastal rivers of eastern North America from Canada to Florida. The sturgeon is a fairly large fish (maximum known length of 56 inches), is long-lived (maximum known age is 67 years), and was commercially important until the 1950s. They prefer the nearshore marine, estuarine, and brackish habitats of large river systems. Shortnose sturgeons, unlike other anadromous species in the region such as shad or salmon, do not appear to make long distance offshore migrations. Principle stressors that have resulted in the severe population decline of the shortnose sturgeon are pollution, incidental overfishing in shad gillnets, construction of dams, and habitat alterations from discharges, dredging, or disposal of material into rivers.





Summary

Estuaries are transitional zones where salt water from the sea mixes with fresh water flowing off the land. Estuaries in the Mid-Atlantic Region provide habitats for many birds, mammals, fish, and other aquatic life. They also are important assets that humans use in a wide variety of ways.

From the information presented in the prior chapters, the complexity and value of the estuarine resources of the Mid-Atlantic Region (circa early to mid 1990s) is apparent. Estuaries are natural mixing bowls for physical, chemical, and biological interactions; and they are threatened by a myriad of human uses. This complexity challenges our ability to understand and manage these great natural resources.

In this report, we have summarized our current understanding of how well estuaries, as a whole, are doing in the Mid-Atlantic Region by presenting information on individual indicators. These individual measures tell us the condition of the Mid-Atlantic estuaries within the context of that particular indicator. A synopsis of our findings follows.

- **Nutrient** concentrations are relatively high in many of the rivers and smaller bays in the Mid-Atlantic estuaries. High nutrient levels are not harmful in themselves; however, overenrichment can cause prolonged phytoplankton blooms that can disrupt estuarine processes. Nonpoint sources such as leaking septic systems, runoff from farms and construction sites, and deposition from the atmosphere are the most common sources of excess nutrients. However, municipal and industrial point sources also contribute large nutrient loads, especially to the Delaware Estuary. Although the Delaware Estuary is one of the most enriched estuaries in the world, harmful phytoplankton blooms are held in check by other factors such as poor water clarity attributed to both natural and human processes. Nutrient loads in Chesapeake Bay are declining, largely in response to improved control of point sources (for example, the upgrading of sewage treatment plants) and bans on certain types of phosphorus detergents. The Delmarva coastal bays are moderately enriched, particularly in Delaware. Coastal waters presently exhibit low nutrient levels, but there is evidence that these levels are increasing. Future progress must focus on controlling nonpoint nutrient sources.
- Prolonged **phytoplankton** blooms can disrupt the growth of submerged aquatic vegetation and promote hypoxia and anoxia in stagnant estuarine waters. High concentrations of chlorophyll during the summer indicate that eutrophication is a problem in the tributaries and upper reaches of Chesapeake Bay and the coastal bays of Delaware and northern Maryland. At present, extended blooms in the Delaware Estuary are uncommon despite high nutrient loadings because phytoplankton growth is limited by the naturally high turbidity in this estuary. The widespread eutrophication that was common in the upper Chesapeake Bay during the 1960s and 1970s has been successfully reduced, in large part by improved nutrient management practices. Eutrophication is increasingly noticeable in the dead end canals along developed shorelines in the Delmarva coastal bays. Chlorophyll levels presently are low in off-shore waters, but there is evidence that levels may be increasing.
- **Dissolved oxygen** (DO) is a fundamental requirement for estuarine organisms. During the critical late summer time period, 17% of the estuarine bottom waters of the region exhibit moderate hypoxia (DO between 2 and 5 mg/L) and 8% exhibit severe hypoxia (DO less than 2 mg/L). Chesapeake Bay is the most hypoxic estuary, largely due to natural processes (water column stratification) made worse by nutrient enrichment and eutrophication. The Delaware Estuary and the Delmarva coastal bays have small areas of hypoxia. Low dissolved oxygen does not appear to be of concern in coastal waters. Poor condition of bottom-dwelling organisms is strongly associated with decreased DO levels.
- **Sediment contamination** with trace metals, PAHs, PCBs, and pesticides, and the associated potential toxicity of these sediments, are considered by the public to be a major threat to estuaries in the Mid-Atlantic Region. More than half of the estuarine sediments in the region have contaminant levels considered to be acceptable. Less than 10% of the sediments contain contaminant levels considered to pose a potential risk of effects to aquatic organisms. Most of the contaminated areas are adjacent to historical urban, industrial, and agricultural sources. In general, sediment contaminant levels in the region have been decreasing over the last decade.

- The historical loss of **coastal wetlands** in the Mid-Atlantic estuaries has largely been stabilized by state and federal conservation plans, even though there is a continuing loss of wetlands in upland areas. The challenge now is to ensure that the wetlands are healthy despite severe anthropogenic stresses. The precipitous loss of **submerged aquatic vegetation** (SAV) in Chesapeake Bay during the 1970s also has been checked. SAV beds are returning to Chesapeake and Chincoteague Bays in response to diminished eutrophication associated with improved nutrient management practices. SAV historically has been absent from the Delaware Estuary and the Delaware portion of the Delmarva coastal bays because of high natural turbidity in these estuaries.
- Impacted **benthic communities** can be found in all of the major estuarine systems of the Mid-Atlantic, but are most prevalent near urban centers such as Philadelphia, Baltimore, Washington, and Norfolk; and in areas suffering from low dissolved oxygen. The most prominent association of impacted benthic communities in Mid-Atlantic estuaries is with low dissolved oxygen concentrations in bottom waters. This condition is located primarily in Chesapeake Bay.
- Harvest of the **American oyster** (*Crassotrea virginica)* traditionally has been one of the major Mid-Atlantic industries but it is now one of the most seriously threatened. The decline in the oyster industry has been precipitous, declining from an annual catch of 133 million pounds in 1880 to about one million pounds today. The primary causes for the recent demise of the oyster fishery are the oyster diseases Dermo and MSX, with overfishing and pollution contributing. Scientists currently are investigating the feasibility and ecological consequences of introducing disease-resistant strains of oysters to Mid-Atlantic estuaries to reestablish the fishery.
- Another important component of the shellfish industry in the Mid-Atlantic region is the **blue crab** *(Callinectes sapidus)*. Annual harvest of blue crabs has been variable over the past decades, especially for the Delaware Estuary. This variability likely is due predominantly to natural environmental factors compounded by fishing pressures. Although the annual catch of crabs has not decreased significantly, the catch per unit effort has. The current harvest is being kept up by increased effort, not neccessarily stable populations. Scientists are concerned because the increased fishing pressure would make it difficult for crab populations to recover if they were impacted by severe environmental conditions such as occurred in the Delaware Estuary in 1977 and 1981 (unusually severe winters).
- Each state monitors their estuarine waters for coliform bacteria and closes those waters to **shellfishing** when the concentration reaches a critical level. Shellfishing is prohibited or restricted in approximately 10% of the 3,660,000 acres of potentially productive shellfish ground in the Mid-Atlantic estuaries. These closings can be attributed to contamination from a variety of sources, including sewage treatment plants, leaking septic systems, marinas, industry, wildlife, boating and runoff. The closings also may be administrative in nature (*e.g.*, inadequate monitoring to ensure the waters are safe). Considering the degree of urbanization in the area, it is encouraging that only a relatively small percentage of the area is closed to shellfishing. In addition, improvements in wastewater treatment have led to a decrease in closed acreage, from 18% in 1985 to 10% in 1995.
- **Fish** abundance, distribution, and condition are considered indicators of ecosystem health because fish integrate effects of environmental stress over space and time. The Mid-Atlantic Region contains many habitat types, making region-wide judgements about fish populations difficult. In addition, market forces and environmental fluctuations obscure causes of fish population declines. Nevertheless, scientists have documented improvements for some species. For example, striped bass and American shad populations are improving after significant historical declines. This is due to reductions in fishing pressure from restrictions that have been, or still are, in effect. Scientists also attribute the observed recovery to improved water quality. Species composition of shore zone fish in the Delaware coastal bays indicate impacted environmental conditions. In contrast, Maryland coastal bays' species composition suggests a healthy habitat; however, researchers have observed evidence of initial degradation in northern areas.
- **Fish and shellfish contaminant levels** throughout the region appear to be decreasing over time due to bans and restrictions on the use of such chemicals as PCBs, DDT, and Kepone and stricter limits on point source discharges. The contaminant concentrations in fish and shellfish generally are at or below the national averages; however, much higher levels may be present in organisms collected near urbanized areas, such as Baltimore Harbor. Generally, contaminant levels in fish and shellfish are higher in the Delaware Estuary than in Chesapeake Bay or the Delmarva coastal bays, perhaps reflecting the degree of urbanization in the estuarine watersheds.
- EPA's Environmental Monitoring and Assessment Program included a pathological examination of 13,467 fish from 177 stations in the Mid-Atlantic

estuaries. Only three per thousand examined were afflicted with **external pathological abnormalities**, indicating a low incidence of such abnormalities. This is considerably lower than the 10 per thousand determined by EMAP for the estuaries of the Gulf of Mexico.

- In general, Mid-Atlantic **waterfowl populations** are in relatively good condition. The major factors affecting these birds are local habitat alteration associated with human development and environmental conditions in other areas along the birds' migratory path. Of some concern is the fact that favorable environmental conditions over the past few years in other parts of the country where migratory birds nest during the summer have resulted in increased populations of those birds, but that increase is not being seen in the Mid-Atlantic. Many of those birds are favoring other wintering sites, such as along the Gulf of Mexico. One possible explanation is habitat loss in the highly developed Mid-Atlantic.
- The Mid-Atlantic Region has experienced some of the most rapid population growth, industrial development, and intensive agriculture in the country. Many organisms relying on the estuaries of the Mid-Atlantic have suffered. In the states surrounding the estuaries of the Mid-Atlantic, numerous species of plants and animals are listed as **threatened** or **endangered** and virtually every county has at least one listed species. It is encouraging that the threatened and endangered species directly associated with the estuaries are improving.

Table 1 is an "environmental report card" for the estuaries of the Mid-Atlantic Region. For the entire region and each of the major systems, we assigned a color representing the condition of individual indicators. These colors represent our best judgment summarization of the information presented in this report. Where multiple colors are shown, our best estimate is that condition ranges between the two categories. Problem areas are determined by individual indicator values. The table does not imply that problem areas are always man-induced.

The pervasive issues across the **Mid-Atlantic Region** include shellfish harvest for oysters and disease in shellfish. Shellfish, particularly the American oyster, traditionally have been one of the major living resources harvested in the Mid-Atlantic states. Oyster harvests have declined from a high of 133 million pounds in 1880 to today's annual catch of about one million pounds. Disease, specifically Dermo and MSX, appears to be one of the major causes of the recent drastic decline in oyster populations in Chesapeake Bay and the Delaware Estuary, with over-harvesting and pollution also playing a major role in Chesapeake Bay. Although no immediate solution to the problem is known, researchers currently are working on the concept of introducing disease-resistant strains of oysters to the Mid-Atlantic. With the decline of the oyster industry, the most important shellfish industry in the Mid-Atlantic Region is now the blue crab. However, the significantly increased fishing pressure on the already heavily exploited population is beginning to take its toll. To avoid a serious impact, both Maryland and Virginia have placed restrictions on crabbing in Chesapeake Bay waters.

The **Delaware Estuary** is characterized by an historical lack of submerged aquatic vegetation (SAV), due predominantly to naturally-occurring low water clarity. It is also one of the most nutrient enriched estuaries in the world, although harmful phytoplankton blooms are held in check by other factors, including low water clarity. The estuary also is highly impacted by lingering toxic contaminants associated with urbanization and industrialization of the Delaware River. The Delaware Estuary has some of the nation's highest levels of chemical contaminants in fish and shellfish. Fishing bans or advisories on the consumption of finfish are posted for portions of the estuary because of elevated PCB concentrations. Concentrations of Chlordane in fish exceeding the FDA action level have been reported in the upper estuary.

Chesapeake Bay continues to be affected by low dissolved oxygen and is the most hypoxic estuary in the region. Low dissolved oxygen levels are associated with nutrient overenrichment and eutrophication. In 1987, the Chesapeake Bay Agreement stipulated a 40% reduction in nutrient loading by the year 2000. Nutrient levels in Chesapeake Bay are declining in response to improved wastewater management practices, implementation of best management practices on agricultural lands (nitrogen), and bans on certain types of detergents (phosphorus). However, there has been more success in controlling point sources than nonpoint sources of nutrients. Historically, high nutrient concentrations have contributed to prolonged phytoplankton blooms in the Bay. Blooms occurring during the 1970s and 1980s significantly reduced water clarity and, as a result, contributed to the massive loss of SAV that occurred during that time period. This critical habitat has since partially recovered.

The **Delmarva coastal bays** are the least degraded systems in the Mid-Atlantic Region but are threatened by encroaching urbanization. The coastal bays are moderately enriched, particularly in Delaware, largely from agricultural sources. Eutrophication is increasingly noticeable in the dead end canals along developed shorelines in the Delmarva coastal bays. SAV historically has been absent from the Delaware portion of the coastal bays because of high natural turbidity in these systems. Species composition of shore zone fish in the Delaware coastal bays indicates impacted environmental conditions. In contrast, Maryland coastal bays' species composition suggests a healthy habitat; however, researchers have

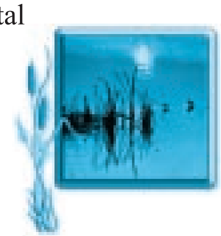
Table 1. Summary of ecological conditions across the Mid-Atlantic estuaries. Colors represent the best estimate of condition based upon information presented in this report—green for good condition, yellow for a moderate problem, and red for a problem. A lack of color indicates that inadequate information was available. Where multiple colors are shown, our best estimate is that condition ranges between the two categories. Problem areas are determined by individual indicator values. The table does not imply that problem areas are always man-induced.

	Mid-Atlantic Region	Chesapeake Bay		Delaware Estuary		Coastal Bays		
		Mainstem	Tributaries	Upper	Lower	DE	MD	VA
Water quality: nutrients	Green–Yellow	Yellow	Yellow–Red	Red	Yellow	Yellow	Green–Yellow	Green
Water quality: phytoplankton	Green	Green	Yellow	Yellow	Green	Yellow	Yellow–Green	Green
Water quality: dissolved oxygen	Yellow	Yellow–Red	Yellow–Red	Yellow	Green	Green–Yellow	Green	
Sediment contamination	Green–Yellow	Green–Yellow	Yellow–Red	Yellow–Red	Green	Yellow	Yellow	
Habitat: coastal wetlands	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Habitat: submerged aquatic vegetation	Yellow	Yellow	Yellow	Red	Red	Red	Yellow	Green
Living resources: benthos	Green–Yellow	Yellow–Red	Green–Yellow	Yellow–Red	Green	Yellow	Green–Yellow	
Living resources: shellfish harvest (oyster)	Red	Red	Red	Red	Red	Yellow	Green	Green
Living resources: shellfish harvest (crab)	Green	Green	Green	Green	Green	Yellow	Yellow	Yellow
Living resources: shellfish closures	Green–Yellow	Green	Yellow	Yellow	Yellow	Green	Green	Green
Living resources: fish stock	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Living resources: contaminants in fish/ shellfish	Yellow	Green	Yellow	Red	Red	Green	Green	Green
Living resources: disease (fish)	Green	Green	Green	Green	Green	Green	Green	Green
Living resources: disease (shellfish)	Red	Red	Red	Red	Red	Yellow	Yellow	Yellow
Living resources: waterfowl	Green–Yellow	Green	Yellow	Yellow	Green	Yellow	Green	Green
Living resources: threatened/endangered species	Green–Yellow	Green	Yellow	Yellow	Green	Yellow	Green	Green

observed evidence of early stages of degradation in northern areas.

Coastal waters presently exhibit low levels of nutrients and chlorophyll. However, evidence suggests that these levels may be rising, indicating the potential for future environmental problems.

The mix of colors in Table 1 indicates that the estuaries of the Mid-Atlantic Region are being impacted. Therefore, they are at risk and in need of active management to restore and maintain environmental quality and sustainable resources. The states, in conjunction with the Chesapeake Bay Program and the National Estuary Programs, have instituted environmental management programs to address these concerns. We now are seeing the positive results of these environmental programs.



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DATABASES AND ORGANIZATIONS

Chesapeake Bay Program

Delaware Department of Natural Resources & Environmental Control

a) Division of Water Resources (shellfish information)
b) Watershed Assessment Branch (contaminants in fish and shellfish)

Haskin Shellfish Laboratory, Rutgers University, Bivalve, NJ

Maryland Department of Natural Resources

Maryland Department of the Environment

NOAA, Chesapeake Bay Office, Fisheries Statistics Database

NOAA, National Marine Fisheries Service, Fishery Statistics Division

U.S. Fish and Wildlife Service

a) Mid-Winter Migratory Bird Survey, Annapolis, MD office (waterfowl information)
b) Endangered Species Home Page http://www.fws.gov/~r9endspp/endspp.html

U.S. EPA, EMAP Database, Environmental Monitoring and Assessment Program-Estuaries database. U.S. EPA, Atlantic Ecology Division, Narragansett, RI.

Virginia Department of Health, Division of Shellfish Sanitation

Virginia Marine Resources Commission

Glossary

Advisory Level: Chemical concentration in fish or shellfish above which consumption of the fish would pose a human health risk. Levels may be determined by various federal or state agencies and may lead to advisories such as restricted consumption or consumption bans. Typical chemicals for which advisories exist include PCBs, chlordane, and dioxin.

Algae: Simple rootless plants that grow in bodies of water (*e.g.*, estuaries) at rates in relative proportion to the amounts of nutrients (*e.g.*, nitrogen and phosphorus) available in the water.

Anadromous Fish: Fish that spend their adult lives in the sea but swim upriver into fresh water to spawn (*e.g*., striped bass, American shad).

Anoxic (anoxia): A condition where very little or no oxygen is present in the water body.

Anthropogenic: Originating from man, not naturally occurring.

Atmospheric Deposition: The flux (flow) of chemicals and materials from the atmosphere to the earth's surface. Depending on the chemical or material, "dry" deposition (*e.g*., by particles) can be less than, equal to, or greater than "wet" deposition (*e.g.*, precipitation).

Benthos: Plants or animals that live in or on the bottom of an aquatic environment such as an estuary.

Bioaccumulation (bioaccumulate): The uptake and storage of chemicals (*e.g*., DDTs, PCBs) from the environment by animals and plants. Uptake can occur through feeding or direct absorption from water or sediments.

Biomagnification: The progressive increase in the concentration of chemical contaminants (*e.g.*, DDTs, PCBs, methyl mercury) from the bottom (*e.g.*, phytoplankton, benthic animals) to the top of the food web (*e.g.*, striped bass).

Brackish: Having a salinity between that of fresh and sea water.

Catch per unit effort (CPUE): A term used in fisheries science to standardize catch information. For example, the CPUE for blue crab harvest might be described as the number of crabs caught per crab pot per day.

Chlorophyll: A group of green pigments found in most plants, including phytoplankton, which they use for photosynthesis. The individual pigment generally measured is chlorophyll *a*. For the sake of clarity we use "chlorophyll" throughout this document; however, we are specifically referring to "chlorophyll *a*."

Coliform bacteria: A group of bacteria primarily found in human and animal intestines and wastes. These bacteria are widely used as indicator organisms to show the presence of such wastes in water and the possible presence of pathogenic (disease-producing) bacteria. *Escherichia coli* (*E. coli*) is one of the fecal coliform bacteria widely used for this purpose.

Community: The assemblage of populations of plants and animals that interact with each other and their environment. The community is shaped by populations and their geographic range, the types of areas they inhabit, species diversity, species interactions, and the flow of energy and nutrients through the community.

Contamination: The impairment of water, sediments, plants, or animals by chemicals or bacteria to such a degree that it creates a hazard to public and environmental health through poisoning, bioconcentration (bioaccumulation), or the spread of disease.

Continental Shelf: A gently sloping submarine plane of varying width between the shoreline of a continent and the continental slope, a steep slope which extends into the oceanic abyss.

Crustacean: Any of various predominantly aquatic arthropods of the class Crustacea, including lobsters, crabs, shrimps, and barnacles, having segmented bodies, a chitinous exoskeleton, and paired, jointed limbs (appendages).

DDT: A group of colorless chemicals used as insecticides. DDTs are toxic to man and animals when swallowed or absorbed through the skin.

Delmarva Peninsula: The land separating Chesapeake Bay from the Atlantic Ocean. The Delmarva Peninsula falls within the states of Delaware, Maryland, and Virginia, from which it gets its name - Delmarva.

Depurate: To cleanse. For example, shellfish contaminated with coliform bacteria can be placed in clean seawater to depurate. Clean water flowing through the organism will remove the bacteria over a period of time. Note that this process does not apply to all contaminants (*e.g.,* chlorinated pesticides).

Dermo: Oyster disease caused by the protozoan parasite, *Perkinsus marinus*.

Detritus: Non-living organic matter (*e.g.*, dead organisms or leaves) in water.

Dissolved Oxygen: Oxygen that is dissolved in water and therefore available for plants (phytoplankton), shellfish, fish, and other animals to use. If the amount of oxygen is too low, aquatic plants and animals may die. Wastewater and naturally occurring organic matter contain oxygen-demanding substances that, when decomposing, consume dissolved oxygen.

Ecosystem: A natural unit formed by the interaction of a community of plants and animals with their environment (physical and biological).

Effluent: The discharge to a body of water from a defined or point source, generally consisting of a mixture of waste and water from industrial or municipal facilities.

EMAP: Environmental Monitoring and Assessment Program - an EPA Office of Research and Development research program.

Endangered: A species that is in immediate danger of becoming extinct and needs protection to survive.

Estuary (estuaries): Regions of interaction between rivers and near-shore ocean waters, where tidal action and river flow mix fresh and salt water. Such areas include bays, mouths of rivers, salt marshes, and lagoons. These brackish water ecosystems shelter and feed marine life, birds, and wildlife.

Eutrophic: Highly productive condition, generally the result of nutrient enrichment in the water column that may cause algae (*e.g.*, phytoplankton) to bloom.

Eutrophication: A condition in an aquatic ecosystem where high nutrient concentrations stimulate blooms of algae (*e.g.*, phytoplankton). Algal decomposition may lower dissolved oxygen concentrations. Although eutrophication is a natural process in the aging of lakes and some estuaries, it can be accelerated by both point and nonpoint sources of nutrients.

Extinct: A species of plant or animal that is no longer living.

Fall Line: A break in the flow of all rivers as they flow from the Appalachian plateau to the Atlantic coastal plain. This region is characterized by the transition of steep, rapidly flowing streams to wider, slower rivers. Large cities are frequently located at the fall line since this represents the upward limit of navigation from the sea.

Fecundity: Fish reproduction potential. Fecundity is usually measured by the number of eggs a female produces.

Filter Feeder: Animals (*e.g.*, clams and oysters) that feed by filtering out of the water column small food items such as detritus, phytoplankton, and zooplankton. Filter feeders also are known as "suspension feeders."

Fish Consumption Advisory: An advisory issued by state government agencies and used to reduce human health risks associated with exposure to chemical contaminants (*e.g.*, PCBs, DDTs, mercury) found in fish and shellfish. Advisories may recommend bans and restricted consumption of specific species in specific geographical areas of an estuary.

Food Web: An assemblage of organisms in an ecosystem, including plants, herbivores, and carnivores, which shows the relationship of "who eats whom."

Habitat: The place where a population or community (*e.g.*, micro-organisms, plants, animals) lives and its surroundings, both living and non-living.

Hot Spot: A problem area or location where pollution, especially a chemical concentration, is very high. Generally located near urbanized areas or point-source discharges.

Hybrid: The offspring of two animals or plants of different races, breeds, varieties, species or genera.

Hypoxia: A condition where very low concentrations of dissolved oxygen are in the water column.

Invertebrates: Animals that lack a spinal column or backbone, including molluscs (*e.g.*, clams and oysters), crustaceans (*e.g.*, crabs and shrimp), insects, starfish, jellyfish, sponges, and many types of worms that live in the benthos.

Land Cover: Anything that exists on, and is visible from above, the earth's surface. Examples include vegetation, exposed or barren land, water, snow, and ice.

Land Use: The way land is developed and used in terms of the kinds of anthropogenic activities that occur (*e.g.*, agriculture, residential areas, industrial areas).

Larvae (larva): Early form of an animal that is unlike its parent and must metamorphose before assuming adult characteristics.

Macroalgae: Non-rooted aquatic plant. Commonly referred to as "seaweed".

Marsh: A wetland where the dominant vegetation is non-woody plants, such as salt grasses and sedges, as opposed to a swamp, where the dominant vegetation consists of woody plants such as trees and shrubs.

Mid-Atlantic Estuaries: In this document, they are defined as Delaware Bay and its tributaries, Chesapeake Bay and its tributaries, and the coastal bays of the Delmarva Peninsula.

Mid-Atlantic Region: For the purpose of this report this is defined as the watershed of the Chesapeake Bay, Delaware Estuary, and the Delmarva coastal bays. It includes all or portions of Virginia, West Virginia, Maryland, Delaware, Pennsylvania, New Jersey, and New York.

MSX: An oyster disease caused by the protozoan parasite, *Haplosporidium nelsoni*.

Nonpoint Source: Refers to pollution that enters water from dispersed and uncontrolled sources, such as surface runoff, rather than through pipes.

Nutrients: Essential chemicals (*e.g.*, nitrogen and phosphorus) needed by plants for growth. Excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae (phytoplankton).

Pathological condition: Abnormal anatomic or physiological condition.

Pesticides: A general term used to describe chemical substances that are used to destroy or control insect or plant pests. Many of these substances are manufactured and do not occur naturally in the environment. Others are natural toxins that are extracted from plants and animals. Chlordane, DDT, and Kepone are examples of pesticides.

Polychlorinated Biphenyls (PCBs): A group of closely related and manufactured chemicals made up of carbon, hydrogen, and chlorine. PCBs can persist for a long time in the environment and they can bioaccmulate and biomagnify in aquatic food webs. PCBs are suspected of causing cancer in humans. They are an example of an organic contaminant.

Phytoplankton: Small, often single-celled plants that live suspended in bodies of water (*e.g.*, estuaries).

Phytoplankton Bloom: A sharp increase in the population of phytoplankton, as often occurs in the spring, summer, or fall in different areas of an estuary.

Point Source: Refers to a source of pollutants from a single point of conveyance, such as a pipe. For example, the discharge from a sewage treatment plant or factory is a point source.

Polycyclic Aromatic Hydrocarbons (PAHs): A class of chemical compounds composed of fused six-carbon rings. PAHs are commonly found in petroleum oils (*e.g*., gasoline and fuel oils) and are emitted from various combustion processes (*e.g.,* automobile exhausts, electric companies).

ppm: Parts per million; equivalent to microgram per gram (μg/g) or milligrams per liter (mg/L).

ppt: Parts per thousand (used as a measurement of salinity).

Recruitment: Entry of fish into a fishery either through the attainment of a size large enough to be taken by a fishery or from an external source (*e.g*., fish entering an estuary from the ocean). Recruitment also can refer to fish reaching sexual maturity for non-exploitable species.

Salinity: A measurement of the amount of salt in water. Generally reported as "parts per thousand" (*i.e.*, grams of salt per 1,000 grams of water) and abbreviated as "ppt" or ‰. Salinity also is reported as "practical salinity units" and abbreviated as "psu."

Salt Marsh: Class of wetlands consisting of salt-tolerant grasses and other plants that are periodically exposed to salt water flooding.

Sediment: Mud, sand, silt, clay, shell debris, and other particles that settle on the bottom of rivers, lakes, estuaries, and oceans.

Seine Survey: A fish capturing procedure where fish are enclosed and drawn to shore using a large net with sinkers on one edge and floats on the other.

Shellfish: An aquatic animal, such as a mollusc (*e.g.*, clams, oysters, and snails) or crustacean (*e.g*., crabs and shrimp), having a shell or shell-like external skeleton (exoskeleton).

Spatial Extent: As used in this document, the total area (water and land) where a condition (*e.g.*, shellfish diseases) or populations of plants and animals are found.

Spawning: Sexual reproduction in fish.

Species: A group of individuals similar in certain morphological and physiological characteristics that are capable of interbreeding and are reproductively isolated from all other such groups.

Stratification: The formation, accumulation, or deposition of materials in layers, such as layers of fresh water overlying higher salinity water (salt water) in estuaries.

Submerged Aquatic Vegetation (SAV): Rooted vegetation that grows under water in shallow areas of estuaries where light can penetrate to the bottom sediments.

Substrate: A surface on which a plant or animal grows or is attached.

Suspended Sediments: Particles of soil, sediment, living material, or detritus suspended in the water column.

Threatened: A species that is likely to become endangered if not protected.

Tidal Mud Flat: The unvegetated shore exposed to air during low tide.

Tissue Residues: Chemical contaminants present in fish or shellfish and usually concentrated in the tissues (*e.g.*, muscle, liver) as opposed to the bones or shell.

Toxic Substances (or material): Chemical compounds that are poisonous, carcinogenic, or otherwise directly harmful to plants and animals.

Trace Metals: Metals such as silver, copper, lead, cadmium, zinc, and mercury that normally occur in water and sediments at concentrations less than one part per million (ppm).

Tributary (Tributaries): A body of water flowing into a larger body of water. For example, the Potomac River is a tributary of Chesapeake Bay.

Trophic level: A grouping of organisms that uses the next lower grouping of organisms as a food source. Used to describe where on the food web (see definition of Food Web in this glossary) organisms feed. For example herbivores feed on plants, and carnivores feed on herbivores.

Turbidity: The clouding of a naturally clear liquid due to suspended solids. Because turbidity reduces the amount of light penetrating the water column, high turbidity levels may be harmful to aquatic life (*e.g.*, SAV).

Virulent: Extremely poisonous or venomous. Regarding a disease, virulent is defined as the ability to rapidly overcome bodily defensive mechanisms.

Water Clarity: Measurement of how far you can see through the water. The greater the water clarity, the further you can see through the water.

Water Column: The water between the surface and bottom of a river, lake, estuary, or ocean.

Watershed: The entire area of land whose runoff of water, sediments, and dissolved materials (*e.g.*, nutrients, contaminants) drain into a river, lake, estuary, or ocean.

Wetlands: An ecosystem type, generally occurring between upland and deepwater areas, that provides many important functions, including fish and wildlife habitat, flood protection, erosion control, water quality maintenance, and recreational opportunities.

Young-of-the-Year: Fish produced in the current year's spawn. Fish less than 1 year old.

Zooplankton: Small, sometimes microscopic animals that float in the water. They feed on detritus, phytoplankton, and other zooplankton. They are eaten by fish, shellfish, whales, and other zooplankton.

Technical Appendix

Criteria used for presenting indicator data

Stratification

Sigma-t is a measure used in physical oceanography to describe water density. It is a measurement of the density that a parcel of water with a given temperature and salinity would have at the surface (*i.e.*, at atmospheric pressure), and is expressed as *(density - 1) * 1000* (Strobel *et al.*, 1995). The degree of water column stratification is determined from the difference in sigma-t between surface and bottom waters. The three categories used to summarize stratification are low (sigma-t difference less than 1), moderate (sigma-t difference between 1 and 2), and high (sigma-t difference greater than 2) stratification.

Water Clarity

The clarity of estuarine water is determined by a measure of the attenuation of sunlight through the water column. It is measured by an attenuation coefficient, which is the natural logarithm of the ratio of the intensity of light of a specified wavelength on a horizontal surface to the intensity of the same wavelength light on a horizontal surface 1 m deeper in the water (Strobel *et al.*, 1995). We define poor water clarity as an attenuation coefficient greater than 2.30, which is equivalent to the transmission of 10% of the light incident on the water surface to a depth of 1 m. Fair water clarity is defined for an attenuation coefficient between 1.39 and 2.30, which is equivalent to the transmission of 25% of the light incident on the water surface to a depth of 1 m. Good water clarity refers to an attenuation coefficient of less than 1.39.

Nutrients

The nutrient levels of Figure 8 show the concentrations of dissolved inorganic phosphate (DIP) and dissolved inorganic nitrogen (DIN, calculated as the combined values of dissolved inorganic nitrate and ammonium ions). These values were measured in surface waters during the summer months. The conditions for Chesapeake Bay reflect data collected annually from 1985 through 1995, while the Delaware Estuary data were collected in 1986 and 1987, and the coastal bays data were measured in 1993.

The classification scale for DIN is: good, < 0.15 mg N/L (ppm); fair, 0.15 - 0.45 ppm; and poor, > 0.45 ppm. For DIP, the scale is: good, < 0.02 mg P/L (ppm); fair, 0.02 - 0.06 ppm; and poor, > 0.06 ppm. For mesohaline waters (medium saltiness, defined as salinities from 5-18 ppt), the criterion for 'good' DIP levels is <0.01 ppm. To be conservative with respect to statistical confidence, a region is classified using the upper limit of its 90% confidence interval. For example, the average DIP and standard deviation in Assawoman Bay is 0.090 ± 0.033 ppm. Thus 90% of all DIP values measured in this bay are 0.156 ppm or less (calculated as the mean plus two standard deviations). Therefore, Assawoman Bay is designated as 'fair' based on this conservative upper limit for DIP.

The boundary between good and fair nutrient categories are the values set by the Chesapeake Bay Program as the criteria necessary to promote continued survival of submerged aquatic vegetation (SAV) in Chesapeake Bay (Chesapeake Bay Program, 1992). The boundary between fair and poor is three times the lower criteria, comparable to the various criteria used in different studies. Caution is advised in drawing conclusions based on these classification limits for several reasons. First, the SAV-related criteria were developed specifically for use in Chesapeake Bay and their applicability in other estuaries is uncertain and currently is under investigation. Also, the relationships between nutrient enrichment and eutrophication are complex and involve more details than were discussed in the text. For example, excess phosphorus promotes eutrophication in the less salty tributaries, while nitrogen encourages blooms in saltier open waters. Therefore, while the 'poor' DIN conditions in the upper Chesapeake Bay and the Delaware Estuary are indications of high nutrient concentrations, they do not necessarily imply high potential for eutrophication. Furthermore, in some places such as the Delaware Estuary, blooms are inhibited by muddy waters despite high levels of nutrients. In summary, Figure 8 is an accurate comparison of nutrient concentrations in the Mid-Atlantic Region estuaries. However, the interpretation of nutrient enrichment with respect to eutrophication should be performed carefully and is an area of active research.

Phytoplankton

Chlorophyll *a* is a measure of the green pigment in phytoplankton. Concentrations of chlorophyll *a* in surface waters measured during the summer months is used to represent phytoplankton levels. The conditions for Chesapeake Bay reflect data collected annually from 1985 through 1995, the Delaware Estuary data were collected in 1986 and 1987, and the coastal bays data were measured in 1993. The scale for the criteria is: good, < 15 mg/L; fair, 15-30 mg/L; poor, > 30 mg/L. To be conservative with respect to statistical confidence, a region is classified according to the upper limit of its 90% confidence interval (see note regarding nutrients for further explanation). The boundary between good and fair nutrient categories are the values set by the Chesapeake Bay Program as the criteria necessary to promote continued survival of submerged aquatic vegetation (SAV) in Chesapeake Bay. The boundary between fair and poor is comparable to the various criteria used in different studies.

Dissolved Oxygen

Dissolved oxygen (DO) is a fundamental requirement for the maintenance of balanced indigenous populations of fish, shellfish, and other aquatic biota. Most estuarine populations can tolerate short exposures to low dissolved oxygen concentrations. However, prolonged exposures to less that 60% oxygen saturation may result in altered behavior, reduced growth, adverse reproductive effects, and mortality. Exposure to less than 30% saturation (~ 2 mg/L for seawater at summer temperatures) for one to four days causes mortality to most biota, especially during summer months, when metabolic rates are high. Stresses that can occur in conjunction with low dissolved oxygen (*e.g.*, exposure to hydrogen sulfide or ammonia) may cause as much, if not more, harm to aquatic biota than exposure to low dissolved oxygen concentration alone. In addition, aquatic populations exposed to low dissolved oxygen concentration may be more susceptible to adverse effects of other stressors (*e.g.*, disease, toxic substances).

The biologically important value is species-dependent, and the regulatory values vary among states in the Region. For comparison purposes in this report, thresholds of 2 and 5 mg/L are used for DO measured in the bottom waters. A concentration of approximately 2 mg/L often is used as a threshold for oxygen concentrations thought to be extremely stressful to most estuarine biota. A threshold concentration of 5 mg/L is used by many states to set water quality standards. The U.S. EPA, as of this writing, has not established DO water quality criteria for estuarine and marine waters, but is in the process of developing the database from which criteria will be developed. Data available for preparation of Figure 13 were from daylight observations. Region-wide estimates of possible night time depression of DO were not available.

Sediment Contamination

Informal guidelines for interpreting sediment contamination based on many field and laboratory studies have been developed. These guidelines attempt to relate observed chemical concentrations to concentrations known to either cause biological effects in laboratory spiked-sediments or spiked-water experiments, or be associated with biological effects in field studies. Examples of these approaches are the Puget Sound (Malek, 1992) apparent effects thresholds (AETs); State of Washington (Phillips, *et al.*, 1988) screening level concentrations (SLCs); Long and Morgan's (1990), as updated in Long *et al.* (1995), effects range median (ER-M) and effects range low (ER-L) concentrations; and refinements to Long and Morgan by MacDonald (1994) for potential effects level (PEL) and threshold effects level (TEL). These approaches benefit from the weight of evidence afforded by large data sets associating sediment contaminant concentrations with biological effect, but suffer from a failure to incorporate the effects of multiple chemicals in complex mixtures, as the chemicals exist in the environment.

While these approaches have shortcomings, they are the best overall benchmarks available for assessing sediment contamination for a wide variety of contaminants. The Long and Morgan ER-Ls and ER-Ms and MacDonald's TELs and PELs are used in this report to summarize sediment contamination in estuaries of the Mid-Atlantic Region. The "no risk" category represents areas with no contaminants in excess of ER-L or TEL values. The "minimal risk" category represents areas with contaminants in excess of threshold ER-L/TEL values but below higher probable-effect ER-M/PEL values. The "potential risk" category represents areas with contaminants in excess of probable-effect ER-M/PEL values. It should be noted that this categorization does not account for the potential role of sub-lethal effects of contamination, such as susceptibility to disease or impairment in growth and reproduction.

Benthic Condition

The numbers of animals of each species observed at a location has been a basic measure used by benthic ecologists to describe the condition of the benthic community. More recently, estuarine scientists have been conducting research on ways to combine individual pieces of information about benthic communities into a single measure that tracks the condition of benthic communities, similar to how the Dow Jones average is used to track the "condition" of the stock market. Two examples of this approach for the Mid-Atlantic Region are the Chesapeake Bay benthic restoration goal index (RGI) and the EPA Environmental Monitoring and Assessment Program (EMAP) benthic index (BI). We have used information from the Chesapeake Bay and EMAP approaches to characterize the condition of benthic communities in the Mid-Atlantic Region.

The RGI was developed by examining benthic communities from areas relatively free of pollution and comparing them with those in areas more affected by pollution (Weisberg *et al.*, 1997). A score is assigned based upon attributes of the benthic community, such as number of species, total number and mass of organisms, presence of organisms in deeper layers of the sediment, and relative abundance of species that are tolerant of pollution. The scores for each of the attributes are averaged to give an overall rating of the community's condition, then aggregated to the following three categories— meets goals, impacted, and severely impacted (USEPA, 1995).

The EMAP BI is an attempt to reduce many individual measures of the benthic community into a single number that has a high level of discriminatory power between good and poor environmental conditions (Strobel *et al.,* 1995; Paul *et al.,* 1997). Independent measures of environmental conditions, such as dissolved oxygen concentrations and sediment contamination levels, are used to select stations that are in good or poor condition for development of the BI. Parameters in the BI include a measure of species diversity and measures of pollution intolerant organisms. A positive BI indicates good conditions, while a negative value indicates impacted benthic community. Severely impacted represents the 10% worst areas as observed by EMAP during 1990-93 (Delaware Estuary Program, 1996).

Fish/Shellfish Advisories

Fish or shellfish consumption advisories are issued by state government agencies to protect human health by reducing the health risks associated with eating fish or shellfish contaminated with chemical pollutants. Advisories are recommendations to limit consumption of certain fish or shellfish taken from contaminated areas. These advisories are issued when the levels of chemical pollutants present in the fish or shellfish exceed an action level. Although states use different methods for calculating the action levels, the common threads are that they are based on the presence of high concentrations of pollutants in the fish or shellfish, and that they are meant to protect human health. Two basic approaches to deriving action levels are: 1) using the U.S. Food and Drug Administration (FDA) action levels; and 2) conducting a risk assessment that factors in such things as typical meal size, frequency of consumption of fish or shellfish, average body weight of consumer, pollutant concentration in the fish or shellfish, and risk of causing cancer. Due to these differences in the calculation of action levels by different states, the fish or shellfish contaminant concentrations in one state's advisory area may not be the same as another state's, but in both areas the concentrations would be high enough to cause concern about possible human health risk. Therefore, fish or shellfish advisories are used in this report to highlight areas of concern rather than to compare contaminant levels in fish and shellfish.

EPA 903-R-98-012 | Condition of the Mid-Atlantic Estuaries | MAIA

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