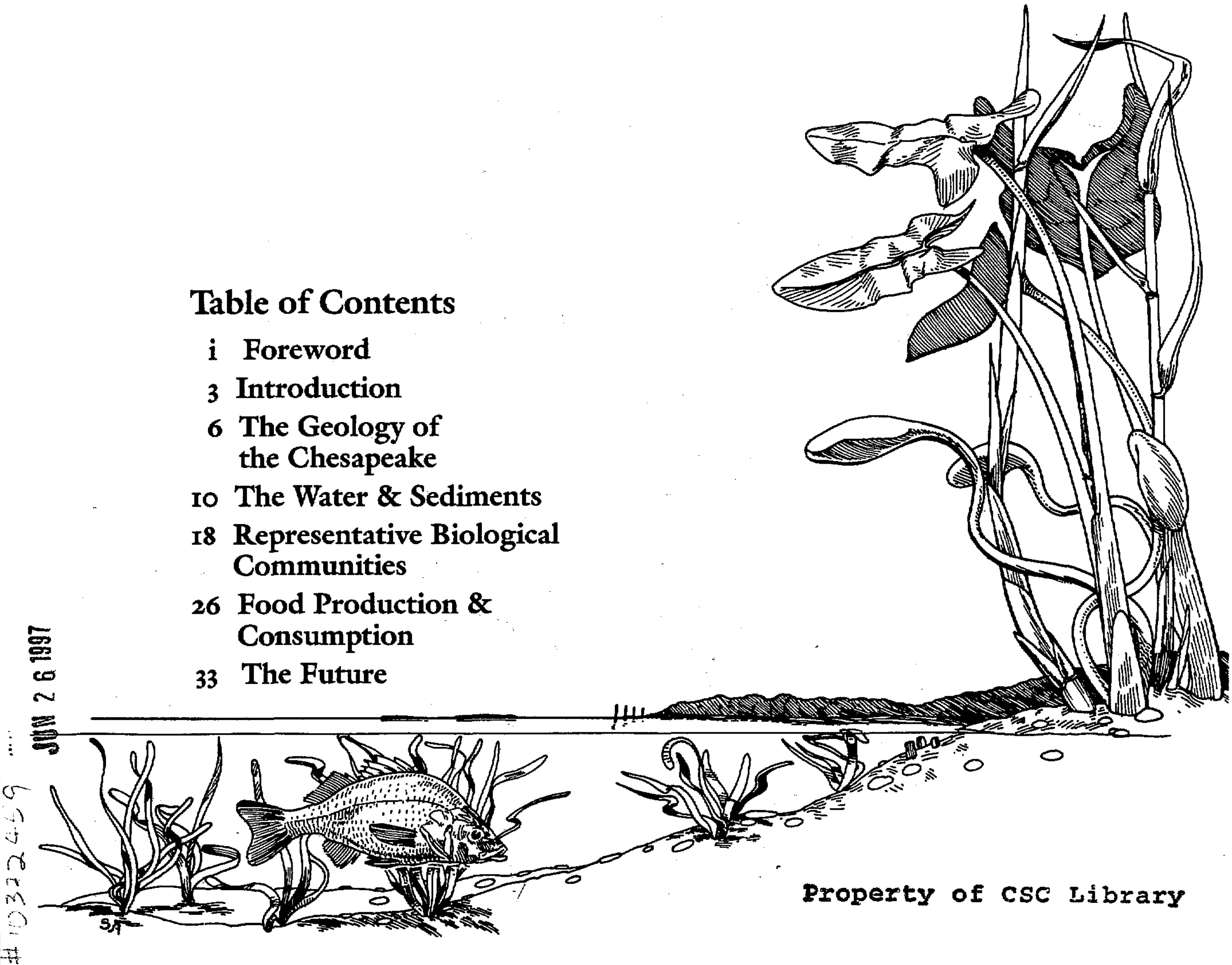
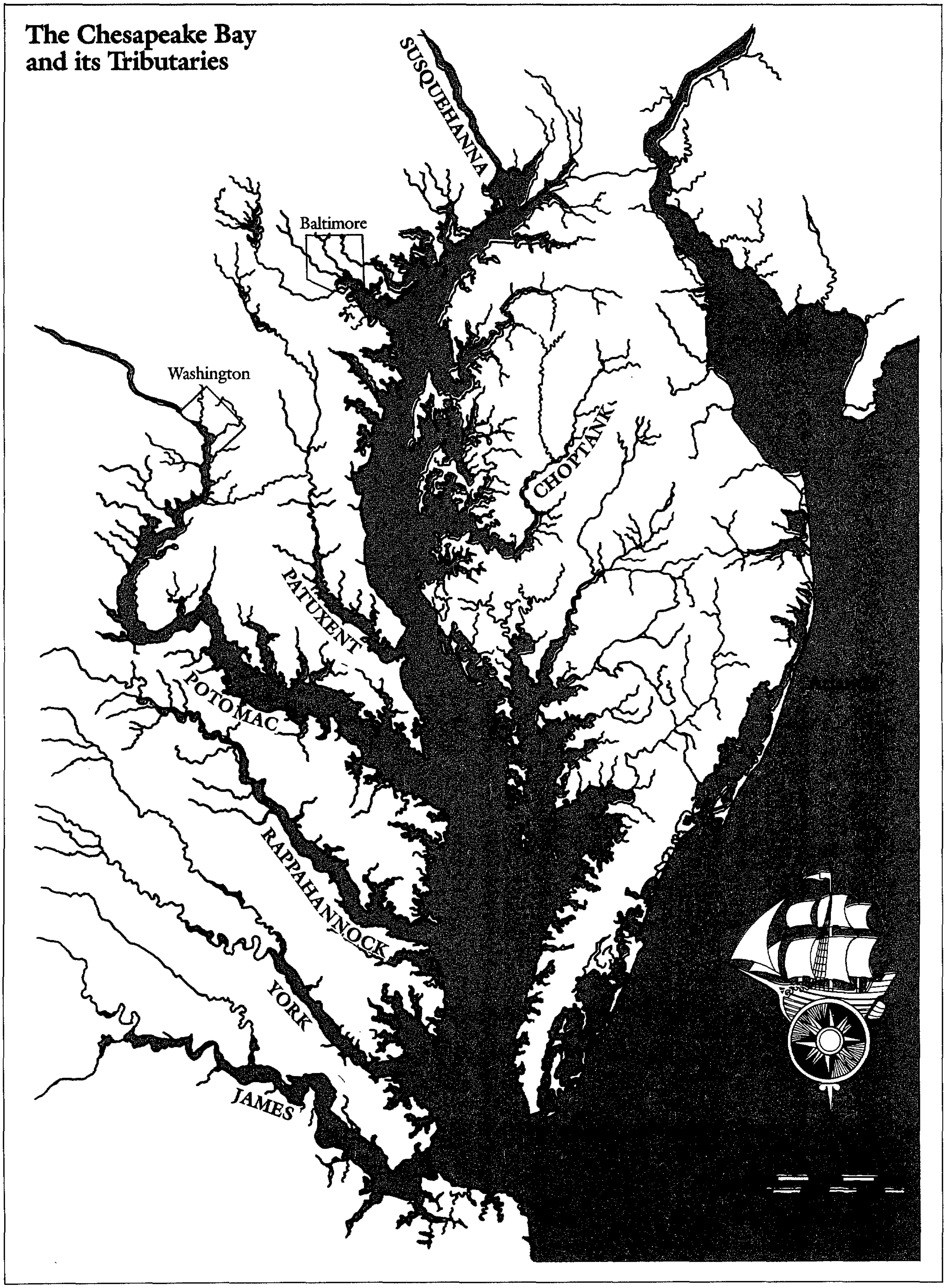
Chesapeake Bay: Introduction to an Ecosystem

Table of Contents

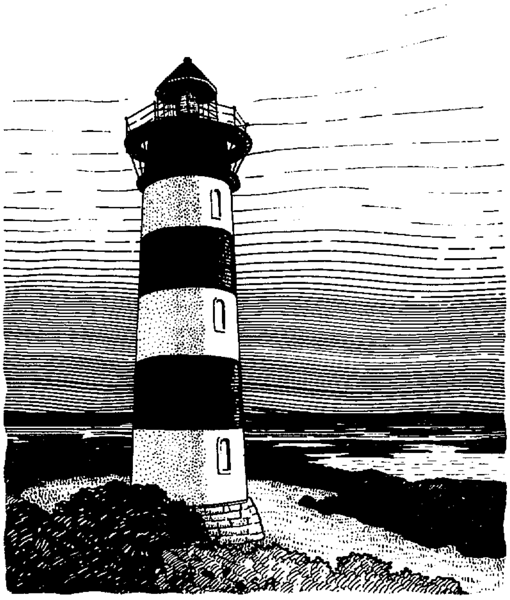


The Chesapeake Bay and its Tributaries



Introduction

Down through the years, residents and visitors alike have found the Chesapeake imposing yet hospitable. The Algonquin Indians called it "Chesepiooc," which loosely translates as the "Great Shellfish Bay." The Spanish explorers named it "Bahia de Santa Maria" and considered it the "best and largest port in the world." Captain John Smith, who first mapped the Bay in preparation for English colonization, extolled the Chesapeake as, "... a faire bay encompassed but for the mouth with fruitful and delightsome land." All were impressed with its size, navigability and abundance of food.



The Bay as an Important Resource

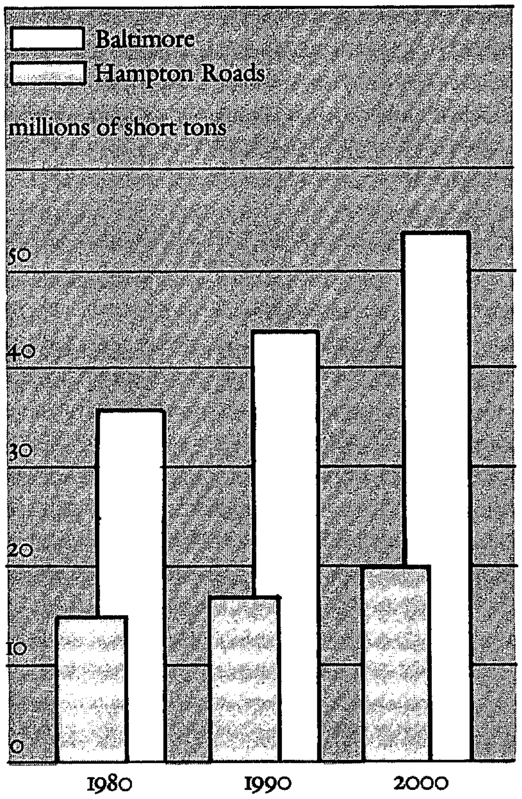
Today, the Chesapeake is still one of this country's most valuable natural treasures. Even after centuries of intensive use, the Bay remains a highly productive natural resource. It provides millions of pounds of seafood, functions as a major hub for shipping and commerce, supplies a huge natural habitat for wildlife, and offers a wide variety of recreational opportunities for residents and visitors.

Chesapeake Bay oysters and blue crabs are widely known delicacies. The average annual oyster catch over the last fifty years has been approximately 27 million pounds of meats per year. Blue crab production totals about 55 million pounds annually, which makes the Chesapeake the largest producer in the world. More than half the total U.S. catch of both soft-shelled clams and blue crabs comes from the Chesapeake, along with more than a quarter of the nation's total yearly oyster catch. A thriving fin-fish industry, primarily based on menhaden and rockfish, rounds out the Chesapeake's major commercial seafood production. The value of the Bay's fishing catch exceeds $100 million annually.

Baltimore's sage, H.L. Mencken once called the Bay, "a great big outdoor protein factory." A recent study by the National Marine Fisheries Service ranks the Chesapeake as third in the nation in overall fishery catch. The Bay's production is exceeded only by the Atlantic and Pacific oceans. That's an impressive ranking, since the Bay covers a much smaller geographic area than the other major U.S. fishing centers.

The Chesapeake is also a key commercial waterway, boasting two of this country's five major North Atlantic ports. The Hampton Roads Complex, which includes Portsmouth, Norfolk, Hampton and Newport News, dominates the mouth of the Bay. At the northern end, the Port of Baltimore handles nearly 24 percent of the export commerce leaving the U.S. North Atlantic ports, making it one of the top three commercial shipping centers on the East Coast. More than 90 million tons of cargo, with a value of nearly $24 billion, were shipped via the Chesapeake during 1979.

Shipping Projections: Chesapeake Bay



Bi-state conference on Chesapeake Bay, 1977.

Both Baltimore and Hampton Roads are situated near the coal-producing regions of Appalachia, making them essential to promoting the use of U. S. coal abroad. The Hampton Roads Complex already leads the nation in exporting coal and lignite.

Nearly 50,000 commercial vessel trips are recorded annually from Chesapeake ports. Shipbuilding and other related industries also depend on the Bay. Industries and power companies use large volumes of water from the Bay for industrial processes and cooling. The estuary also assimilates wastes from some of these industries as well as municipal wastes generated by the 13 million people who live within the Chesapeake watershed.

Perhaps one of the Chesapeake's most valuable functions, yet one that is difficult to put a price tag on, is its role as a major wildlife habitat. The Bay and surrounding wetlands provide a home for a myriad of plants and animals.

Migratory birds and waterfowl use the Bay as a major stop along the Atlantic Flyway. Here they find food and shelter in the numerous coves and marshes. The Chesapeake is also the winter home for approximately half a million Canadian geese and more than 40,000 whistling swans. It is a nesting area for the endangered bald eagle and the osprey, whose largest U. S. population is found in the Bay region.

The Chesapeake's tributaries provide spawning and nursery sites for several important species of salt-water fish, such as the white perch, striped bass and shad. During the warmer months, several marine species including bluefish, weakfish, croaker, menhaden and spot enter the Bay to feed on its rich food supply.

The hospitable climate, lush vegetation and natural beauty of the Chesapeake have made it an increasingly popular recreation area. Boating, fishing, swimming, hunting and camping are the major attractions. Both power and sail boating have grown dramatically. In 1979, more than 122,000 pleasure craft were registered in the State of Maryland alone.

Sportfishing is another major recreation activity in the Chesapeake. A 1979 survey by the National Marine Fisheries Service estimated the annual sportfish catch at 28 million, which accentuates the value of the Bay as a breeding ground for desirable species of sportfish.

Defining the Chesapeake

As well as being a national resource, the Chesapeake Bay is the largest estuary in the contiguous United States. The Bay itself is only part of an interconnected system which includes the mouths of many rivers draining parts of New York, Pennsylvania, West Virginia, Maryland, Delaware and Virginia. The Bay and all of its tidal tributaries comprise the Chesapeake Bay ecosystem. We are just now beginning to see the effects of human activities on the Bay's ecological structure. To assure the Chesapeake's continued productivity, we must develop comprehensive solutions to the often conflicting demands on the Bay's resources. Growing commercial, industrial, recreational and urban activities in the Bay area are putting substantial pressures on the Chesapeake's regenerative powers.

Some potential problems are becoming apparent. For example, the bay grasses, which perform so many crucial functions within the Bay ecosystem, are declining in many areas. The oyster catch is diminishing and kepone and other chemicals have shown up in the biota of the Bay. In addition, algal blooms have become more prevalent in the Bay and its tributaries.

To determine the causes of, and potential remedies for, those problems it is necessary to see the Bay from a new perspective. All too often we think of ourselves as external to our environment and ignore the many relationships between humans, other living creatures and their surroundings. If such relationships are ignored in determining solutions to environmental problems, more and greater problems may result. For example, after World War II, DDT was widely applied in the Bay area to control mosquitoes. An unexpected consequence was that the DDT interfered with egg shell development in several species of birds. Since the ban on widespread use of DDT, some species such as the osprey have begun to increase in numbers. Solutions to the environmental problems are far more effective when they take into account the complex relationships involving all of the components of the ecosystem.

When environmental problems are approached from an ecosystem perspective, proposed solutions to specific problems are evaluated in light of their effect on all other elements within the system. A truly effective solution not only corrects the problem, but avoids damaging other elements or relationships within the ecosystem. This approach makes problem-solving a great deal more challenging, but leads to more effective environmental management.

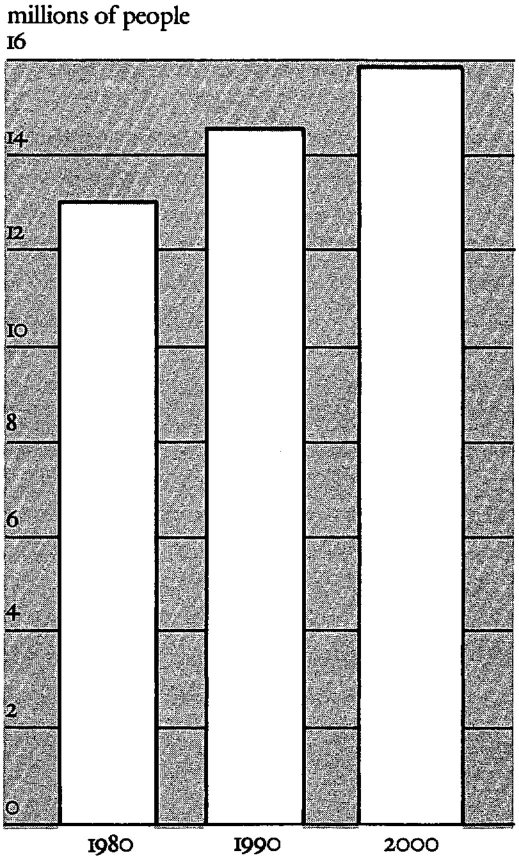
In order to adequately define the Chesapeake ecosystem, we must go far beyond the actual shores of the Bay itself. The make-up and problems of the entire drainage basin significantly impact the functions and inter-relationships of the Bay proper. The weather, air, land, water, plants and animals all form a complex web of interdependencies which together make up the Chesapeake ecosystem. Lest we forget, humans are also an important and very dependent part of this overall system.

The purpose of this publication is to provide a glimpse of this complex system along with enough background information to allow the reader to understand the general processes involved. In order to simplify the presentation, we have divided the discussion into four major areas of interest:

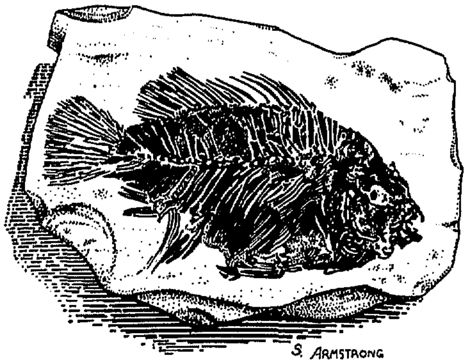
- **Geological Make-Up**—This section traces the geologic history of the Bay, describes the overall physical structure of the Bay proper and covers important aspects of the entire watershed.
- **Water & Sediments**—This chapter reviews the estuarine processes, describes the physical characteristics and chemical properties of the Bay waters, and examines the composition and distribution of sediments.
- **Key Biological Communities**—Here we discuss major plant and animal populations living within the Bay itself, the communities in which they reside; and the ways in which they interact.
- **Food Production and Consumption**—This chapter explains the production of carbon by plants and how organisms use carbon and other nutrients to make food. In addition, it explains how carbon used by plants is distributed through the various trophic levels.

Together, these chapters provide the reader with an appreciation for the interactions between the land, water and living creatures of the Bay.

Population Projections: Chesapeake Bay Drainage Basin



The Geology of the Chesapeake



The Chesapeake Bay as we know it today is the result of thousands of years of continuous change. Since its creation following the end of the last ice age, the Chesapeake ecosystem has been subjected to an unending modification process. Nature, like a dissatisfied artist, is constantly reworking the details. Some modifications enhance the Bay. Others seem to detract from it; but all affect the ecosystem and its interdependent parts. Some changes are abrupt, while others take place over such a long period of time that we can only recognize them as modifications by looking back into geologic history.

Humans are becoming more involved in the reshaping process, often inadvertently initiating chains of events which reverberate through the Bay's ecosystem. Because our actions can have a potentially devastating effect on the entire system, it is essential that we develop an adequate understanding of the Bay's geological underpinnings.

Geologic History

In geological terms, the Chesapeake is very young. If the entire geological calendar from the earliest fossil formations were equated to one year, the Bay would be less than a minute old.

During the latter part of the Pleistocene epoch (which began a million years ago), the region encompassing what is now the Chesapeake was alternately exposed and submerged as massive glaciers advanced and retreated up and down the North American continent, causing sea levels to fall and rise in concert with glacial expansion and contraction. The region still experiences small-scale changes in sea level, easily observed over the duration of a century.

The most recent retreat of the glaciers, which began about 10,000 years ago, marked the end of the Pleistocene epoch and brought about the birth of the Chesapeake Bay. The melting glacial ice resulted in a corresponding increase in sea level that submerged coastal areas including the Susquehanna River Valley along with many of the river's tributaries. This complex of drowned stream beds now forms the basin of the Chesapeake Bay and its tidal tributaries.

The Chesapeake Basin

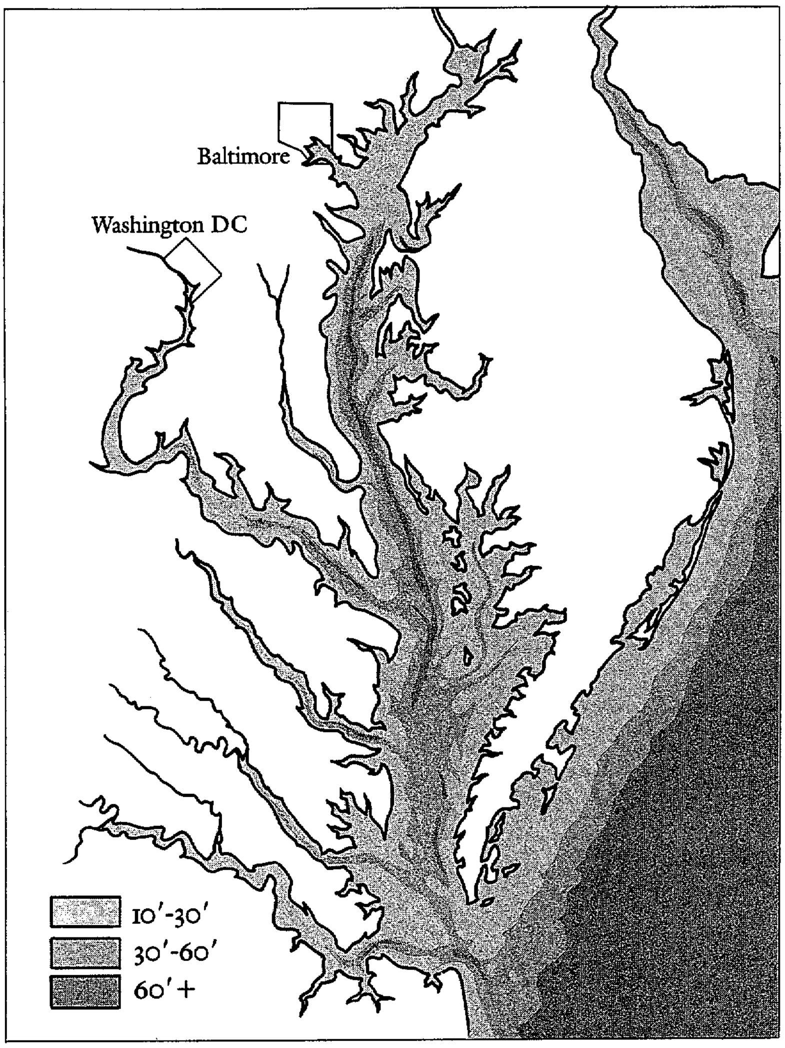
The Bay proper is approximately 200 miles long and ranges in width from about four miles near Annapolis, Maryland to 30 miles at its widest point near the mouth of the Potomac. The water surface of the Bay proper encompasses more than 2,200 square miles. When its tributaries are included that figure nearly doubles. On average, the Chesapeake holds about 18 trillion gallons of water. If the entire tidal Bay system were drained, it would take more than a year to refill with water from rivers, streams and runoff.

Fifty major tributaries pour water into the Chesapeake every day. Almost 90 percent of the freshwater entering the Bay comes from the northern and western sides. The remaining 10 to 15 percent is contributed by the eastern shore.

Although the Bay's length and width assume dramatic proportions, the depth is another matter. The average depth is less than 30 feet. In general, the Bay is shaped like a very shallow tray except for a few deep troughs which are believed to be remnants of the ancient Susquehanna River Valley. Fortunately, these troughs provide a rather deep channel which runs along much of the length of the Bay. Because it is so shallow, the Chesapeake is far more sensitive to temperature fluctuations and wind than is the open ocean.

Even though the Bay proper lies totally within the Atlantic Coastal Plain, it draws water from an enormous 64,000 square-mile drainage basin which also includes part of the Piedmont Plateau, and the Allegheny Plateau. More than 50 tributaries contribute water to the Chesapeake, providing a mixture of waters with a broad geochemical range. The Bay is influenced by both the Atlantic Coastal Plain and the Piedmont Plateau, two radically different geological structures, each contributing a characteristic mixture of minerals, nutrients and sediments.

The Atlantic Coastal Plain, whose waters drain directly into the Bay, is a relatively flat, low land area with a maximum elevation of about 300 feet above sea level. It extends from the edge of the continental shelf on the east, to a fall line that ranges from 15 to 90



The deepest parts of the Bay lie down its center and in some of the larger tributaries. These areas are believed to be remnants of the ancient Susquehanna River Valley, and are potential areas for accumulation of sediments which may contain toxic materials.

miles west of the Bay. This fall line forms the boundary between the Piedmont Plateau and the coastal plain. Waterfalls and rapids clearly mark this line, where the elevation sharply increases to approximately 1,100 feet, due to the erosion of the soft sediments of the coastal plain.

Cities such as Fredericksburg, Richmond, Baltimore and Washington, D.C. have developed along this fall line, taking advantage of the water power potentials of falls and rapids.

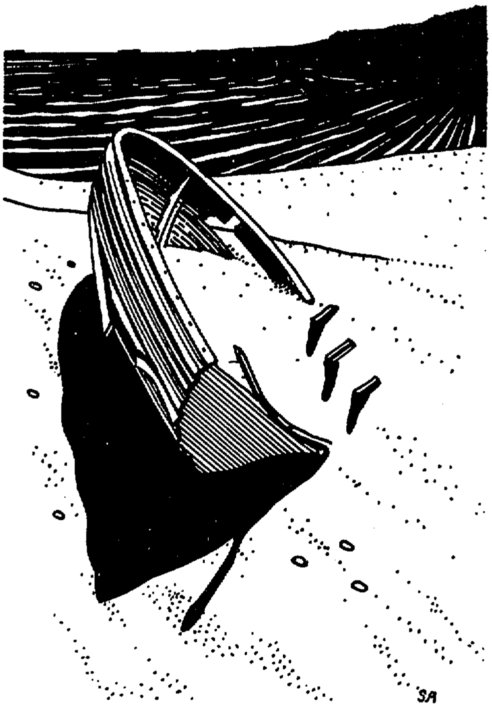
The Atlantic Coastal Plain is supported by a bed of crystalline rock, covered with southeasterly-dipping wedge-shaped layers of relatively unconsolidated sand, clay and gravel. Water passing through this loosely compacted mixture easily leaches out the mineral content. The most soluble elements are iron, calcium and magnesium. Waters of the Coastal Plain average moderately soft to moderately hard, although extreme local levels of hardness can and do occur here.

The Piedmont Plateau ranges from the fall line in the east to the Appalachian Mountains in the west. This area is divided into two geologically distinct regions by Parrs Ridge, which traverses Carroll, Howard and Montgomery Counties in Maryland and adjacent counties in Pennsylvania. The eastern side is composed of several types of dense crystalline rock, including slates, schists, marble, and granite. This results in a very diverse topography. Rocks of the Piedmont tend to be relatively impermeable, and waters from the eastern side are usually soft and flow directly into the Bay.

The western side consists of sandstones, shales and siltstones, underlain by limestone. This limestone bedrock contributes calcium and magnesium to its water, making it hard. Waters from the western side of Parrs Ridge flow into the Potomac River, one of the Bay's larger tributaries.

Clearly, the waters that flow into the Chesapeake Bay have a chemical identity that significantly depends on the geology of their place of origin. In turn, the nature of the Bay itself depends on the characteristics and relative volumes of these contributing waters.

Erosion & Sedimentation

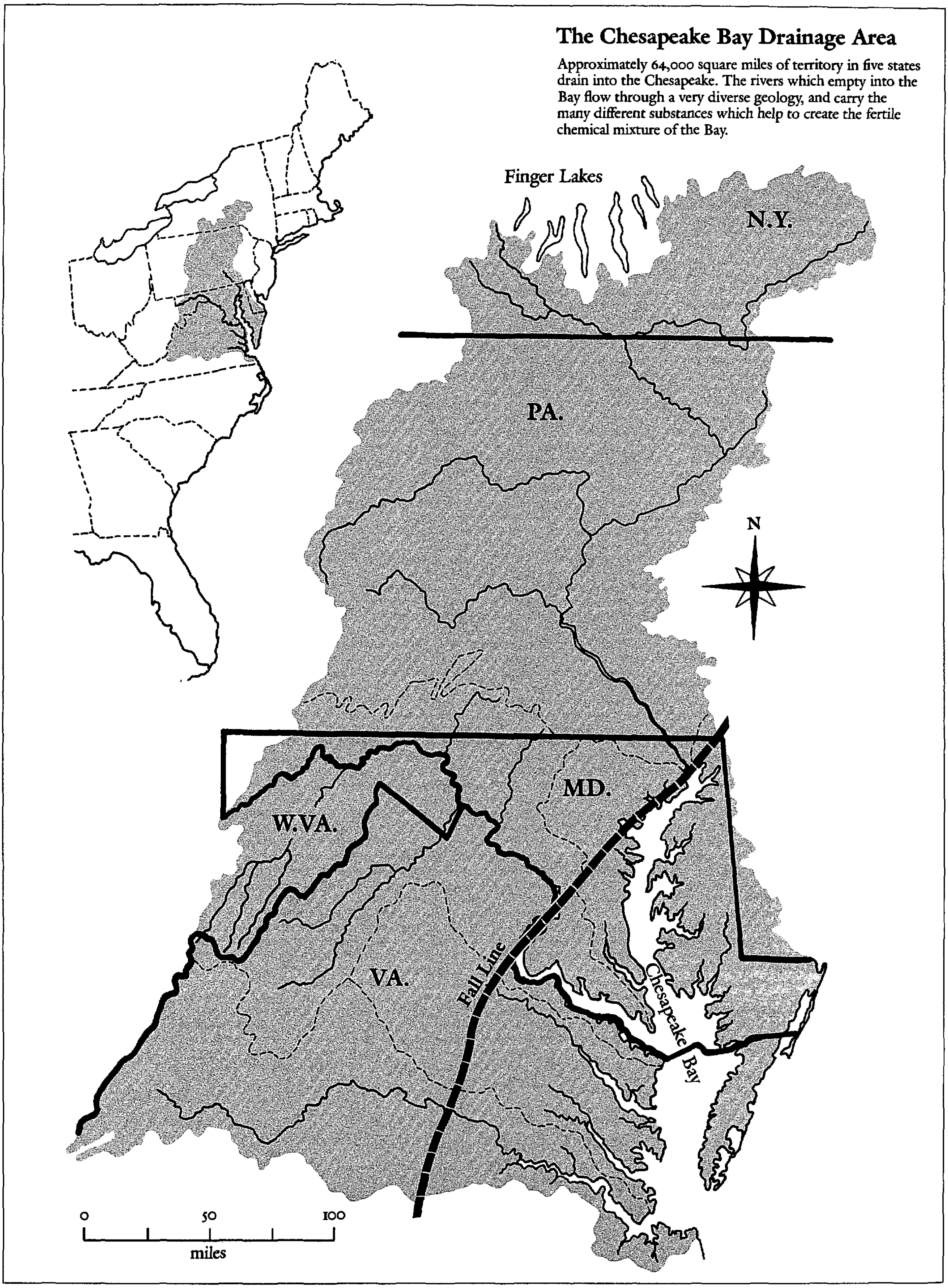


Since its creation, the Chesapeake's shoreline has undergone constant modification by erosion, transport and deposition of sediments. In this process, areas of strong relief, like peninsulas and headlands, are eroded and smoothed by currents and tides, and the materials are deposited in other areas of the Bay. Sediments carried by the river currents are left at the margins of the Bay and major tributaries, resulting in broad, flat deposits of mud and silt. Colonization by marsh grasses stabilizes the sediments, and marshes develop. Land build-up in the marshes continues until the area becomes part of the shoreline.

The speed at which these modifying processes progress is determined by a multitude of factors, including weather, currents, composition of the affected land, tides, wind and human activities.

The story of Sharp's Island, off the eastern shore of the Chesapeake, provides a telling example of the power and swiftness of erosion in the Bay area. In colonial times, the island was a rich plantation of six hundred acres. Today, it is completely submerged, a victim of erosion. Sharp's Island disappeared so quickly that some longtime residents of the eastern shore can still remember seeing the white frame hotel that was situated on it.

The forces of erosion and sedimentation are continually reshaping the details of the Bay.



The Chesapeake Bay Drainage Area

Approximately 64,000 square miles of territory in five states drain into the Chesapeake. The rivers which empty into the Bay flow through a very diverse geology, and carry the many different substances which help to create the fertile chemical mixture of the Bay.

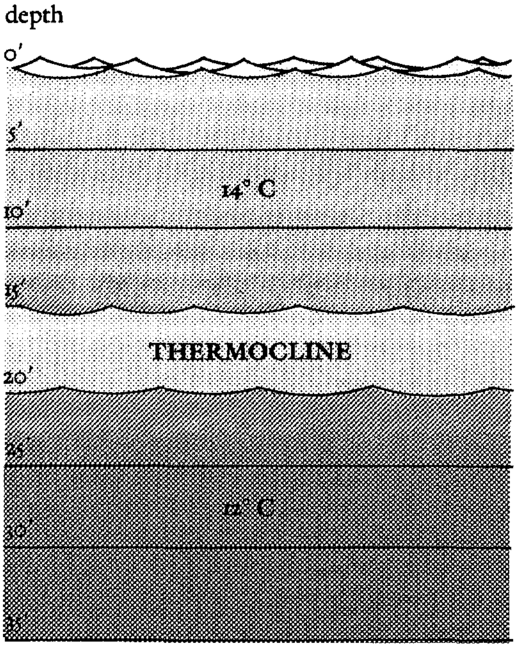
The Water & Sediments

Water . . . four-fifths of the earth's surface is covered by it. It makes up approximately 80 percent of our total body weight. Without it, we cannot survive. Perhaps, because its presence is so pervasive in our lives, we tend to think of water as being homogenous rather than as a substance with extremely diverse characteristics and properties.

Pure water is composed of two atoms of hydrogen bound to one atom of oxygen. However, in nature water is never pure. It tends to hold other substances in solution and easily enters into various chemical reactions. It is this proclivity for "impurity" that makes water an excellent environmental medium. Water normally contains dissolved gases such as oxygen, as well as a wide variety of organic (containing carbon) and inorganic materials. The concentration and distribution of these "impurities" can vary widely within a single body of water. Add differences in temperature and circulation which can enhance or retard certain chemical reactions, and the variety of possible water environments vastly increases.

Of all bodies of water, estuarine systems offer the greatest diversity in water composition. An estuary, according to oceanographer Donald W. Pritchard, is a "semi-enclosed body of water which has free connection with the open sea and within which sea water is measurably diluted by freshwater from land drainage." Within an estuary, freshwater mixes with salt water, each contributing its own variety of chemical and physical characteristics. The mixing of fresh and salt waters creates unique chemical and physical environments, each of which supports different communities of organisms particularly suited to that type of water. The greater the number of different environments available within a body of water, the greater the variety of life that is likely to be sustained therein.

Typical Vertical Temperature Profile in Spring
(April-May)

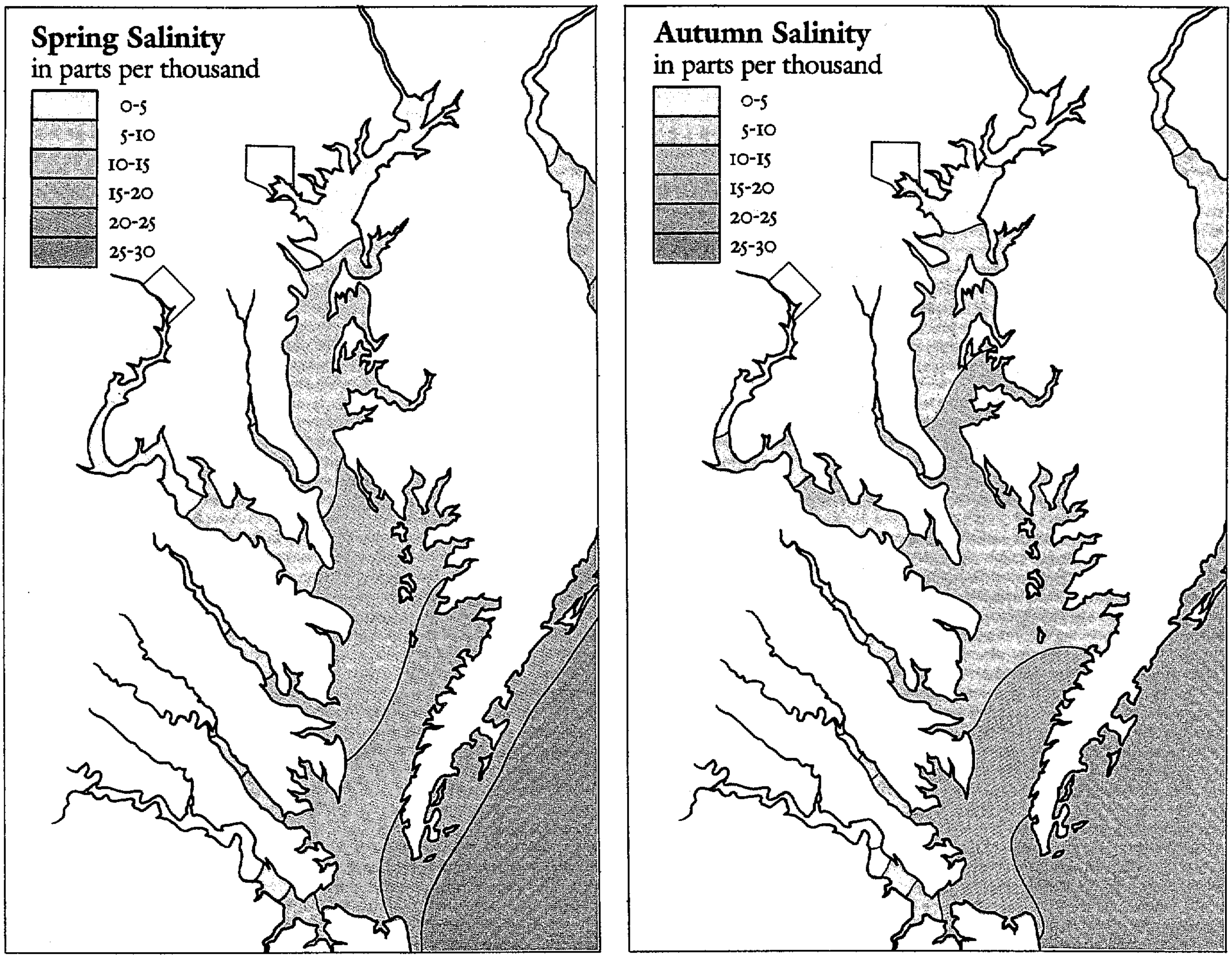


Water: Temperature, Salinity & Circulation

The distribution and stability of Bay environments depends on three very important physical characteristics of the water — temperature, salinity and circulation. Each affects and is affected by the others, and together they determine the physical characteristics of the water at any given point in the Bay.

Temperature dramatically affects the rates of chemical and biochemical reaction within the water. A 10-degree Celsius (18-degrees Fahrenheit) increase in temperature can double the speed of many reactions. Because the Bay is so shallow, its capacity to store heat over time is relatively small. As a result, water temperature fluctuates considerably, ranging from 0-degrees C to 29-degrees C (32-degrees F to 84-degrees F) over the annual cycle. Fluctuations such as this are significant because water temperature in turn affects other processes such as spawning which is partially regulated by water temperature.

The Bay's vertical temperature profile is fairly predictable. During the spring and summer months, the surface waters are warmer than



With the heavy influx of freshwater in the spring, the surface of the Bay declines in salinity. As freshwater flow declines in the autumn, salinity from seawater increases.

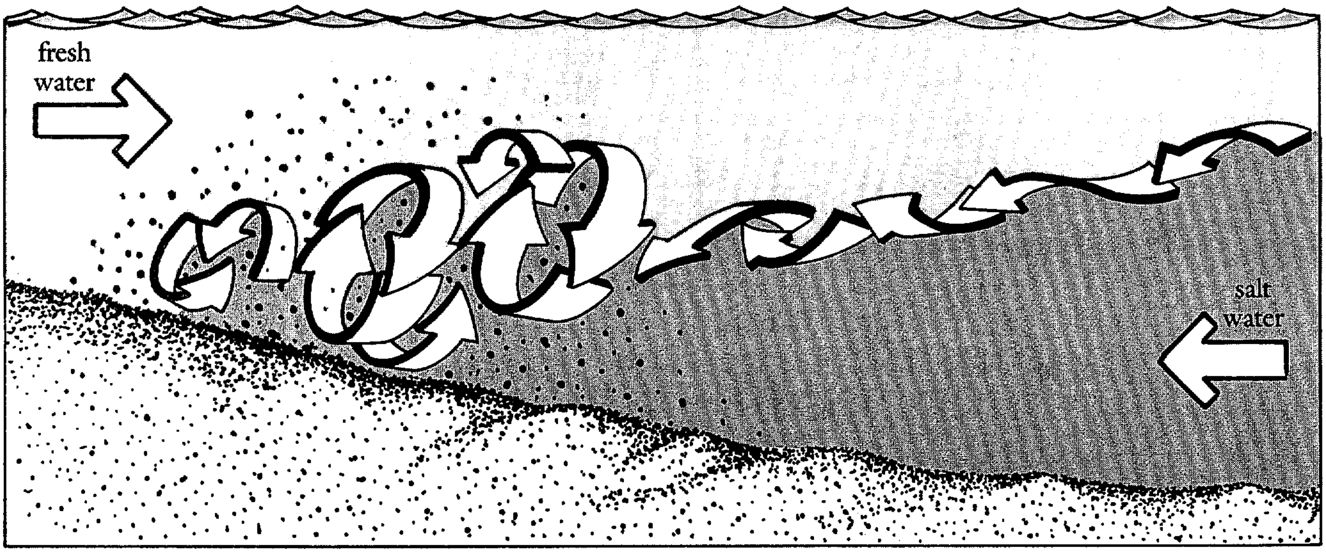
the deeper waters, due to the warmth of the sun. The water temperature gradually decreases in relation to depth until a point is reached where the temperature drops abruptly. That point is known as the thermocline. Below the thermocline, the temperature again resumes its gradual drop, until the coldest depths are reached at the bottom. Often by June, the turbulence of the waters helps to break down this layering and to cause the thermocline to lose definition.

In the fall, the warming radiation of the sun begins to diminish. As the surface water cools, it increases in density, becoming heavier. Once the surface water becomes colder and denser than the water toward the bottom, it begins to sink and vertical mixing occurs. Wind may speed up the process. This mixing action can bring nutrients, materials essential to the growth of organisms, up from the bottom and into higher water levels. The turn-over makes the nutrients available to phytoplankton and other organisms inhabiting the upper water levels.

During the winter, the water temperature becomes relatively constant from surface to bottom until March, when the process of surface warming begins again.

Salinity is the second key factor affecting the physical make-up of the Bay. It is the concentration of dissolved salts in the water, usually expressed in parts of salts per 1,000 parts of water (ppt). Freshwater contains few salts (drinking water usually has a salinity of less then 0.5 ppt), while seawater averages 35 ppt.

Two-Layered Circulation Pattern with Zone of Maximum Turbidity



Since seawater enters the Bay through its mouth (located at the southeastern edge), the salinity is highest at that point and gradually diminishes as one moves toward the northern end. The salinity levels within the Chesapeake vary, depending on the volume of freshwater that flows into the Bay. Salinity declines in the spring when rainfall, groundwater and melting snow cause large increases in freshwater inflows. For example, the volume of the Susquehanna River, which contributes about 50 percent of the Bay's freshwater, can vary 15-fold on a seasonal basis. In the fall, when freshwater inflows are greatly reduced, high levels of salinity extend farther up the Bay.

Salinity can be indicated on a map or chart by lines called isohalines. These lines connect points in the water which have the same salinity. Because the greatest volume of freshwater enters the Bay from the northern and western tributaries, the isohalines tend to show a marked southwest to northeast tilt. This means higher salinity levels extend farther up the Bay on its eastern side. To a lesser extent, the effect of the earth's rotation, called the Coriolis force, also influences this tendency toward higher salinity levels along the eastern shore.

Salinity levels are graduated on a horizontal plain from one end of the Bay to the other. They are also graduated vertically from top to bottom. Since the presence of salts increases density, the lighter freshwater tends to remain at the surface, while salinity increases with depth. However, the relationship between depth and salinity is not constant. From the surface to the bottom, salinity increases gradually, but there may be an intermediate layer where the increase in salinity is abrupt. This layer is known as the halocline. It normally separates the less saline surface layer from the high saline bottom layer. As such, it also distinguishes two different types of environments.

Perhaps the most important aspect of the Chesapeake's graduated salinity levels is their effect on the distribution and well-being of the various biological populations living in the Bay.

Estuarine circulation is also extremely important. The movement of the waters transports plankton, eggs of fishes, shellfish larvae, sediments, dissolved oxygen, minerals, nutrients and other chemicals.

Freshwater from rivers, streams and run-off affects salinity. This effect is the primary factor driving circulation of the Bay and tidal tributaries. In the upper Bay and upper reaches of tidal tributaries, freshwater flows seaward over a layer of saltier, denser seawater flowing inward. The opposing movement of these two flows forms saltwater fronts, or intrusions, which move up and downstream primarily in response to freshwater inflow.

These fronts are characterized by intensive mixing. The most vigorous mixing occurs near the head of the Bay and its major tributaries and causes suspension of bottom muds. Sediment particles, including inorganic, dead organic and living plankton, move seaward in the surface flow, then sink into the upstream-flowing saline water. The particles mix with the suspended muds and create a zone known as the turbidity maximum. Nutrients are mixed in the turbidity maximum, making these zones highly productive.

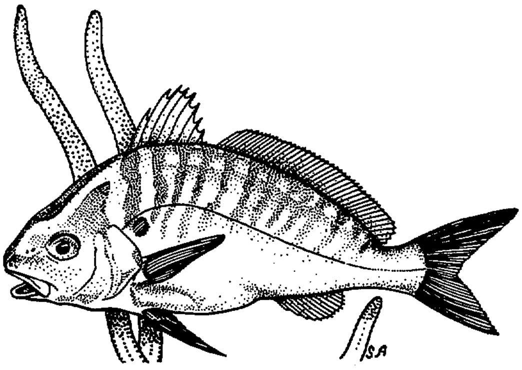
Meteorological or tidal forces can alter this circulation pattern. The two-layered flow (fresh above, saline below) or stratification is strongest in the spring when freshwater inflow is greatest. The flow of freshwater slows down in the fall when there may be no distinct layers at all. Stratification may also vary within any season depending on rainfall or catastrophic events such as hurricanes. In addition, the tides are sometimes strong enough to mix the two layers.

For the lower Bay, the two-layered circulation breaks down into a more complex pattern. The location of the major rivers, as well as the earth's rotation (Coriolis force), cause freshwater to accumulate along the western shore. Salinities on this side are thus lower than they are to the east. The two layers are tilted so that the freshwater stays mainly on the western shore. The result of this process is a more fully mixed water column in the lower Bay. Here ocean water enters the Bay through the northeastern side of the Bay's mouth, and freshwater escapes primarily on the southwestern side of the mouth.

Weather influences the circulation of the Bay system by disrupting the typical two-layered flow. Wind plays a role in the mixing of the Bay's waters. Another significant factor is barometric pressure, which depresses or raises the level of surface waters. Wind and barometric pressure can change the nature of the classic two-layered circulation, occasionally reversing flow direction for short periods of time. For example, strong, northwest winds associated with high pressure areas push water away from the coast, creating exceptionally low tides. Exceptionally high tides, on the other hand, result when strong northeast winds associate with low pressure areas.

There are some other notable exceptions to this basic circulation pattern. Circulation of the smaller tributaries does not always follow the two-layered pattern outlined above. These very small tributaries, such as the Bush and Gunpowder, are flushed by tidal exchange, with little chance for stratification.

The intermediate and larger tributaries of the upper Bay, such as the Patapsco (Baltimore Harbor), Chester, and Patuxent may have three distinct layers of flowing water at their mouths. This pattern may occur during the spring, when the Susquehanna River pours large volumes of freshwater into the mouths of these tributaries at the surface. This forces the surface freshwater to flow back upstream. The heavy, saline water from the deep channels of the Bay's main stem flows up the tributaries along the bottom. In the meantime, a layer is created in the middle at the mouth of the tributary. This layer contains a mixture of the top and bottom layers and flows outward with the water coming from the tributary itself.

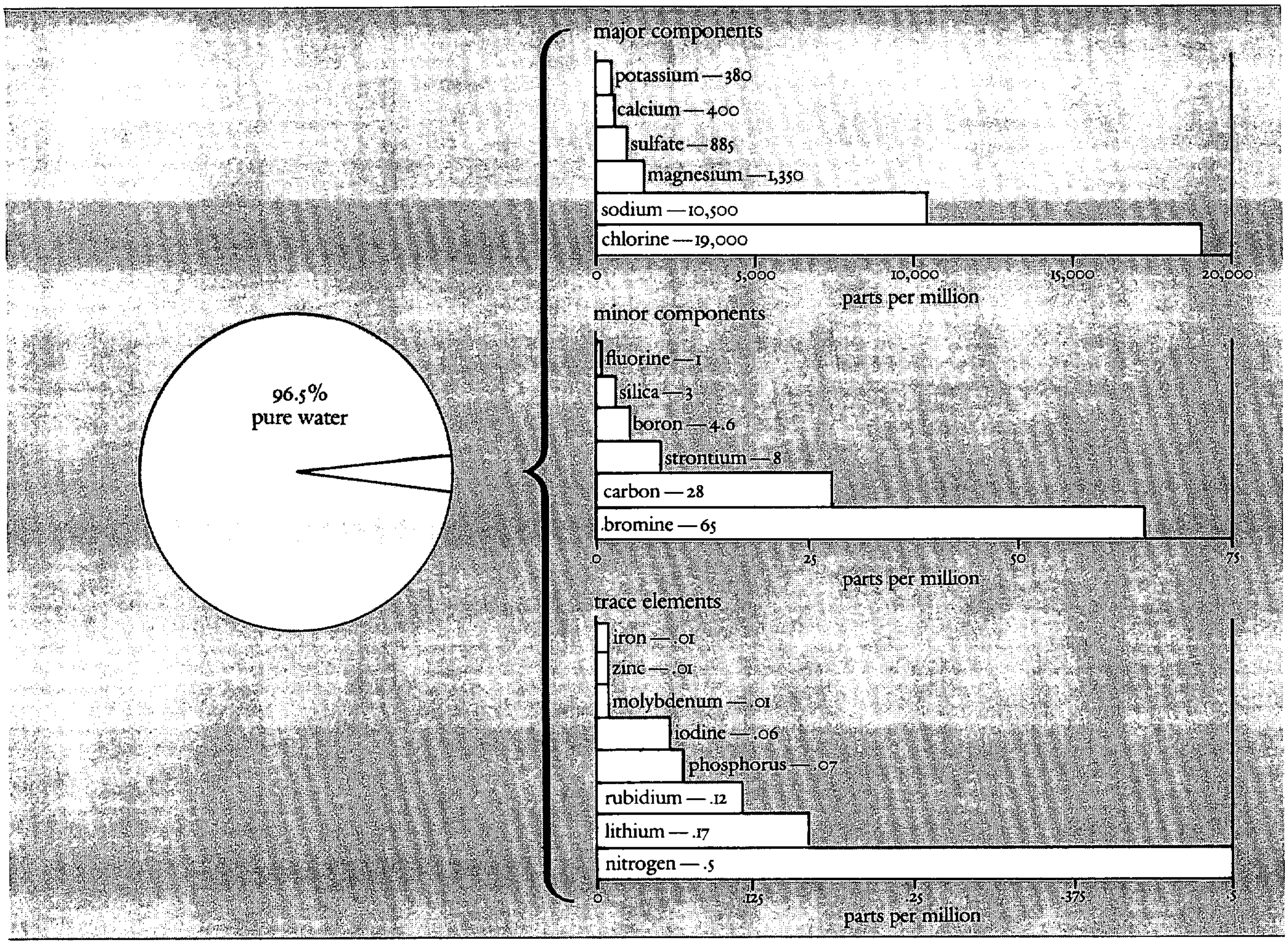


Chemical Factors

This section examines the chemistry of the Bay's waters and provides a background for understanding food production in the Chesapeake. These chemical processes play a major role in defining physiological limits to the relative abundance and distribution of plants and animals within the Bay. In this context, it is important to remember that many constituents contribute to the dynamic balance among organisms, water and sediments.

The waters of the Chesapeake are a complex chemical mixture, containing dissolved organic and inorganic materials, including dissolved gases, nutrients and a variety of other chemicals. The more saline waters of the Bay are chemically similar to ocean water. Seawater contains six major natural chemical components—chlorine, sodium, magnesium, calcium, sulfate, potassium, with sodium chloride (salt) dominating. Ocean water also contains many minor elements, including cobalt, manganese, iron, molybdenum and silica. These elements are important in many biological reactions. For example, in minute quantities, cobalt is required for living organisms to make vitamin B_{12}. Heavy metals such as mercury, lead and cadmium usually occur naturally in very low concentrations. In some areas, though, human activities add heavy metals to the water in quantities large enough to create serious pollution problems.

Dissolved Inorganic Compounds in Seawater



Some of the components of sea water are "conservative"—they do not react easily with other chemicals and are not taken up by plants or animals. Their concentration is relatively constant. Sodium chloride is conservative, while the nutrients, nitrogen, and phosphorus, change seasonally. These conservative elements provide a good measure of the extent of mixing between freshwater and seawater. In the Bay, salinity of 17.5 ppt indicates seawater has been diluted 50 percent by freshwater.

Concentration of the major constituents of seawater is relatively constant from place to place. Freshwater, by contrast, contains a variable composition of salts that depends on the soils and rocks the water has come in contact with on its way to the Bay. Sodium chloride is negligible in freshwater. Silicon, however, which is important in the cell wall structure of diatoms (one-celled plants), occurs at higher concentrations in Susquehanna River water than in ocean water.

Among the important chemical constituents found in waters of the Chesapeake are: organic and inorganic materials, dissolved oxygen, carbon dioxide, nitrogen and phosphorus. Both fresh and salt water contain a myriad of natural dissolved organic materials. These natural compounds are only now being identified, and are believed to be the breakdown products of proteins, carbohydrates and fats from plankton and higher organisms such as fish. These breakdown products come from several sources. Microorganisms decompose dead organisms and release dissolved organic compounds to Bay waters. Organisms are also "leaky" and excrete many organic compounds directly into the water. In addition, dissolved organic material flows into the Bay via its tributaries.

Many of these organic compounds are required (at extremely low concentrations) for the growth of phytoplankton, microscopic plants found in open waters. For example, vitamin B_{12} may occur at one nanogram per milliliter (or approximately 1 part in a billion) and still meet the growth requirements of many organisms. Some natural organic compounds also serve as chelators. This means that they are attracted to, and bind with, metals like iron. This keeps the metals in solution and biologically available.

Synthetic (man-made) organic materials, some of which are toxic, may also be added to the waters of the Bay system. Many chemical wastes of industries and sewage treatment plants, as well as most herbicides and pesticides, are organic chemicals.

Inorganic dissolved salts (such as sodium chloride) are important to the adaptive processes of many organisms. Some fish spawn in fresh or slightly brackish water and must move to more saline waters as they mature. These species have internal mechanisms which enable them to cope with the changes in salinity. In addition to being biologically important, natural dissolved materials also affect the physical properties of water such as lowering its freezing point or increasing its density.

Dissolved oxygen is essential for all plants and animals inhabiting the Bay. However, it is a particularly sensitive constituent because other chemicals present in the water, biological processes and temperature exert a major influence on its availability during the year. The maximum amount of oxygen which can be dissolved in a given unit of water increases as the water becomes colder and decreases as the water becomes more saline. For example, at 15 degrees Celsius, one liter of seawater has a saturation level of 5.8 milliliters of dissolved oxygen, while one liter of freshwater can hold 7.1 milliliters.

Oxygen is transferred from the atmosphere into the surface waters by the aerating action of the wind. It is also added at or near the surface as a by-product of plant photosynthesis. As a result, floating and rooted aquatic plants increase dissolved oxygen levels. Since the existence of plants also depends on the availability of light, the oxygen-producing processes occur only near the surface or in shallow waters.

Surface water is at or near oxygen saturation all year long, while deep bottom waters range from saturation to nearly anoxic (no oxygen present). During the winter, respiration levels are relatively low. Vertical mixing is good and there is very little salinity stratification. As a result, dissolved oxygen is plentiful throughout the water column. During the spring and summer, increased levels of animal and microbial respiration, greater salinity stratification and reduced vertical mixing result in low levels of dissolved oxygen in deeper water. In fact, the deeper areas of some tributaries, such as the Patuxent and the Potomac, can become anoxic in the summer. Later, when the surface waters cool in the fall, vertical mixing occurs and the deep waters are reoxygenated to their winter condition.

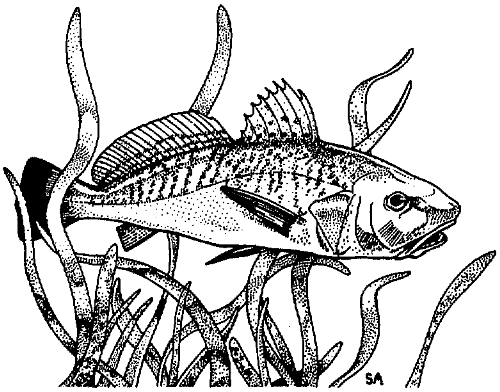
Carbon dioxide, another dissolved gas, is important to the well-being of the Bay's aquatic environment, acting as a buffer against rapid shifts in acidity. Such shifts can be detrimental to both plant and animal life in the Bay. Carbon dioxide is also essential to plant life in the Bay because it provides the carbon with which plants produce new tissue during photosynthesis. Like oxygen, carbon dioxide is highly soluble in water. Its availability is also affected by temperature and salinity in much the same fashion as oxygen.

Nitrogen is one of the major constituents in the production of plant and animal tissue. Its primary role is in the synthesis and maintenance of protein. The nitrogen enters the ecosystem in several chemical forms, including ammonia, nitrate and nitrite, although the preferred nutrient form for the growth of Bay phytoplankton is generally ammonia. Nitrogen also occurs in other dissolved organic and particulate forms, such as living and dead organisms.

Some bacteria and blue-green algae can extract nitrogen gas from the atmosphere and transform it into organic nitrogen. This process, called nitrogen fixation, is an important pathway in the cycling of nitrogen between organic (living) and inorganic components.

Phosphorus is another key nutrient in the Bay's food system. It is found in the water as dissolved organic and inorganic phosphorus as well as in particulate form. This nutrient is essential to cellular growth and reproduction. Phytoplankton and bacteria assimilate and use phosphorus in their growth cycles. Phosphates are the preferred form, but other simpler forms of organic phosphorus are also used when phosphates are unavailable.

When phosphates are highly concentrated in waters which contain oxygen, they combine with iron and suspended particles and eventually settle to the Bay bottom, becoming unavailable to phytoplankton and temporarily excluded from the cycling process. Phosphates sometimes become long-term constituents of the bottom sediments. Phosphorus compounds in Bay waters generally occur in greater concentrations in less saline areas, such as the upper portion of Bay tributaries. Overall, phosphorus concentrations range more widely in the summer than winter.



Just as fertilizer aids the growth of agricultural crops, both nitrogen and phosphorus are vital to the growth of plants within the Bay. These two elements are supplied in significant quantities by sewage treatment plants, food processing industries and urban, agricultural and forestry run-off. They are generally needed in a ratio of 16 parts nitrogen to one part phosphorus. If the availability of either drops below this general ratio, it becomes the limiting factor in the growth of plant life.

Too many nutrients, on the other hand, can lead to an overabundance of phytoplankton, creating dense populations, or blooms, of plant cells. Blooms of green or blue-green phytoplankton can become a nuisance in the upper tidal freshwaters of some tributaries. As the blooms decay, oxygen is used up in decomposition. This can lead to anoxic (and odorous) conditions.

This situation can be improved. For example, in the upper tidal freshwater Potomac in recent years, minimum levels of dissolved oxygen have not been as low as they were during the 1960's and early 1970's, and algal blooms have decreased. This is at least in part attributable to the installation of new sewage treatment facilities in the mid 1970's. These installations significantly reduced the amounts of phosphorus entering the Potomac estuary, perhaps restoring some limits on the algal growth.

Sediments: Composition & Effects

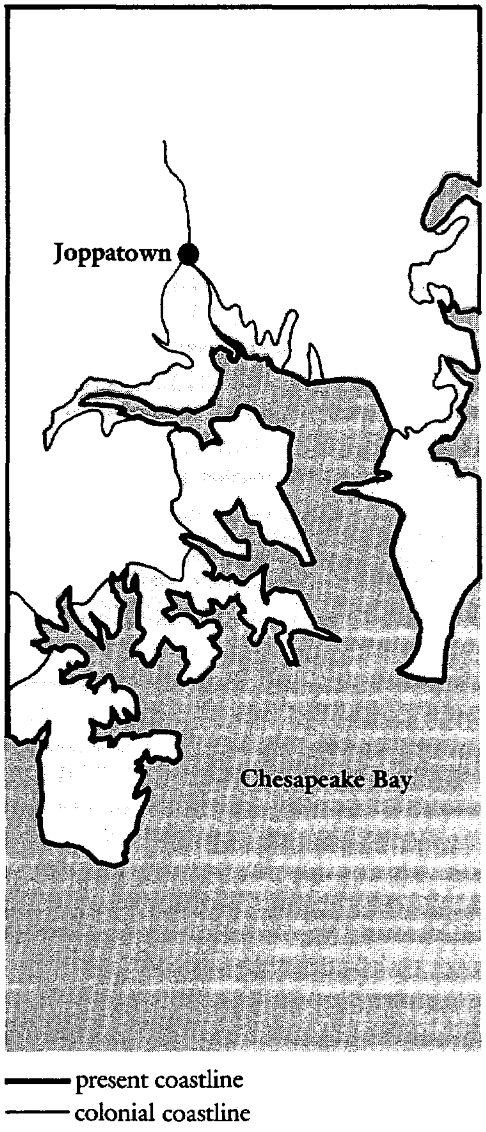
In addition to chemicals, nutrients, and other dissolved materials, the waters of the Chesapeake and its tributaries also transport huge quantities of particulate matter known as sediments, which are composed of organic and inorganic materials. Sediments are distributed by the Bay's circulation system.

Researchers are particularly interested in the sediments and how they travel through the Bay because sediments can contain high concentrations of certain toxic materials. Individual sediment particles have a large surface area, and many molecules easily adsorb, or attach, to them. As a result, sediments can act as chemical sweeps by adsorbing metals, nutrients, oil, pesticides and other potentially toxic organics. Thus, areas of high sediment deposition may well have high concentrations of persistent (long-lasting) chemicals.

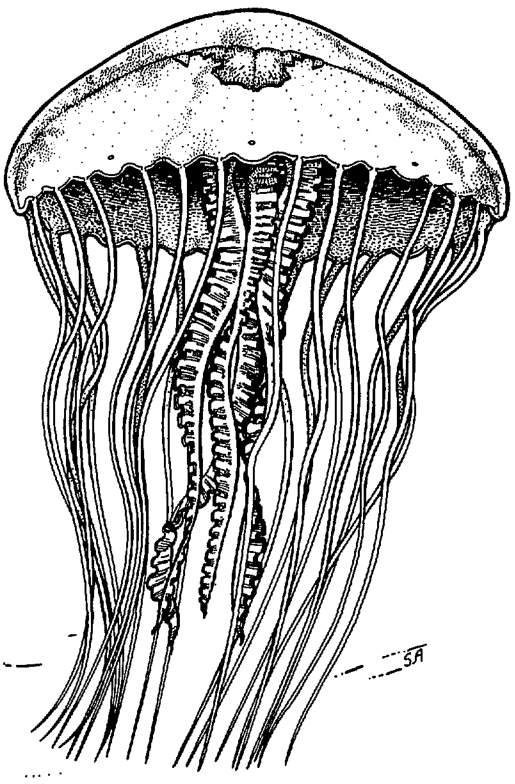
While essential to the habitats of many Bay organisms, accumulation of sediments is, in many ways, undesirable. Accumulation of sediments on the bottom fills in waterways and ultimately leads to the filling of the Bay. This sedimentation process has already caused Port Tobacco and Joppatown, Maryland, seaports during colonial times, to become landlocked. As they settle to the bottom of the Bay, the sediments can smother the benthos (bottom dwelling plants and animals). In addition, suspended sediments contribute to the turbidity of the water and thus decrease the light available for plant growth.

The upper and lower sections of the Chesapeake have different sedimentation problems. In the upper Bay, the sediments discharged by rivers are primarily fine-grained silts and clays which are relatively light and can be carried long distances. Due to the two-directional water circulation pattern which is predominant in the upper Bay, these sediments are discharged into the fresh upper layer of water. As they move into the Bay, these particles slowly descend into the denser saline layer, where they reverse direction and flow back up into the tidal tributaries along with the lower layer of water. As the upstream flow terminates, the sediments settle to the bottom, mainly in the areas of maximum turbidity, thus turning these estuarine reaches into very effective sediment traps.

In the lower Bay, by contrast, the sediments are somewhat sandier, and heavier. These particles result primarily from shore erosion. They drop fairly rapidly to the bottom, remain near their original source and are less likely to be resuspended than are finer silts.



Representative Biological Communities



More than 2,700 species of plants and animals inhabit the Chesapeake and its shoreline. All depend on the Bay and their fellow inhabitants for food and shelter. Each, in turn, contributes to the continued life of the entire Chesapeake ecosystem.

Each type of organism (species) has a set of physical and chemical requirements that must be satisfied in order for it to live. Different species have different requirements for temperature, water, salinity, nutrients, substrate, light, oxygen and shelter. These physical and chemical variables largely determine which species will be found in a particular habitat.

Within every habitat, communities of organisms are found which exist in a close relationship with each other. Some provide shelter. Others serve as prey or act as predators. The functions within a given community are almost endless, and the Chesapeake provides countless communities both large and small.

The composition of each community, or group of species, undergoes change in population density due to environmental factors and interactions among species. Germination of new plants, birth of new animals, growth, changes in life stages (i.e., larval fish to juvenile), local movement, migrations and stress due to changes in water quality, habitat, over-fishing or other human activities are some of the factors responsible for those fluctuations. Such change is characteristic of most ecological communities and is true of the Chesapeake Bay. Each species within a given community is subject to major or minor population fluctuations with varying frequencies.

Some variations, such as seasonal changes in abundance, or the size of populations, follow a predictable pattern. Others apparently follow longer-term patterns or fluctuate randomly. Experience and studies have shown that for a given season one can expect a characteristic representation of species, although a few species may be missing at any specific instant.

Some Bay communities are prone to rapid fluctuations in numbers of one or more member species. This is particularly true for plankton whose growth rate is correlated with their small size. Rapid changes in diversity and abundance may occur hourly or daily—a complex result of interacting biological, physical and chemical factors.

Many species show a long-term pattern in population abundance and distribution. For example, striped bass were relatively rare in the Bay during the 1930's and early 1940's, while the croaker was abundant. The bass increased until the early 1970's, when the population began to decline. Its reduced numbers were followed by an increase in bluefish, another predator. Such population cycles illustrate why it is so difficult to separate natural patterns from those induced by human activity.

Bay communities can be as small as an oyster bar or as large as the entire Bay. But whatever the size, these communities overlap and intertwine with each other.

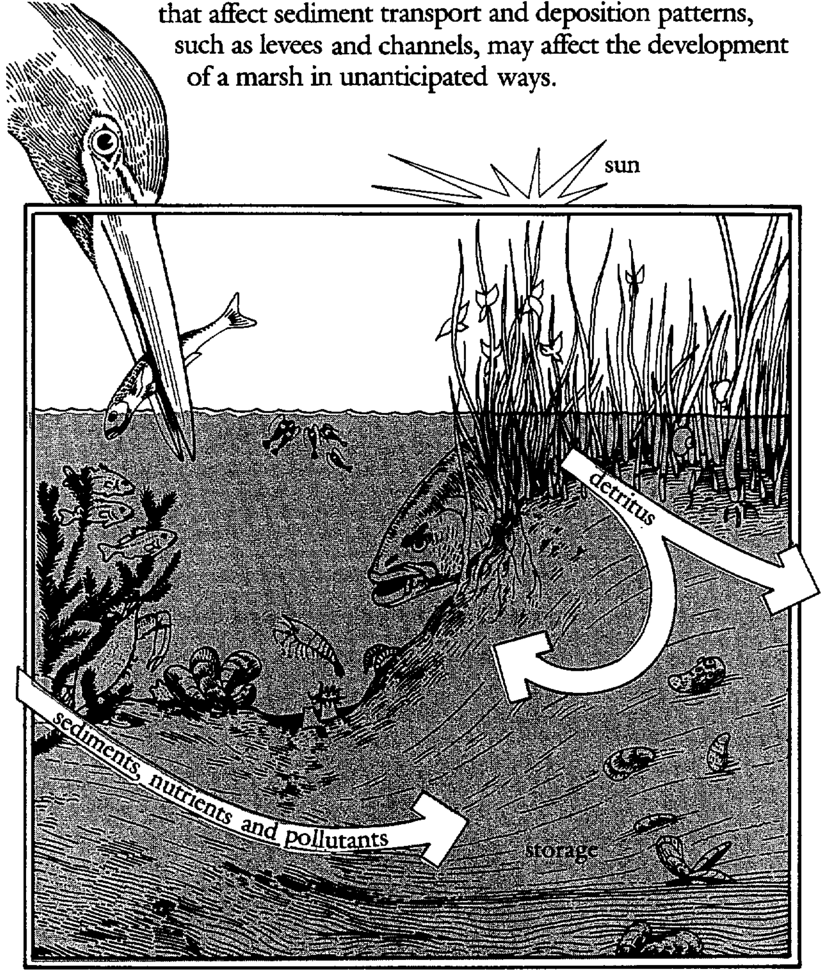
Five major Bay communities that interact closely are the marsh dwellers, bay grass inhabitors, plankton, bottom residents and swimmers. Each community represents a particular habitat within the Bay, and these habitats exhibit a wide range of characteristics. The marshes are relatively stable areas along the shoreline. The bay grass community extends from about mean low tide to a depth of about ten feet or when light becomes limiting. The plankton community is composed of minute creatures that float and drift with the movement of the water. The benthic environment includes the bottom of the Bay and its residents. Finally, the nekton are the fish and other swimmers who move freely throughout the Bay.

Each of these five communities—marsh, bay grass, plankton, bottom and swimming—along with the roles they play and how they interact, are described in the following sections.

Marsh Dwellers

Marshes fringe the Chesapeake and its tributaries, encompassing about 425,000 acres, with 212,000 acres in Maryland and 213,000 acres in Virginia. Forming a natural boundary between land and water, these spongy areas are dampened by rain, groundwater seepage, adjacent streams and by the Bay's tides. They are transitional areas that may slowly be converted to solid shoreline or may disappear due to erosion.

Marshes help to reshape the Bay by removing sediments from the waters. Their emergent plants trap the sediments that they receive from streams and from tidal flooding. Without a rising sea level the growth of the marsh would be slow or nonexistent. Human activities that affect sediment transport and deposition patterns, such as levees and channels, may affect the development of a marsh in unanticipated ways.



The Marsh Community

The marsh habitat harbors a seasonally abundant assemblage of plants and animals. The mid-salinity marsh shown here has a lower number of plant species than tidal fresh marshes, but ecological processes are representative. For example, intense feeding by fish and birds occurs and nutrients, sediments and detritus are exchanged with surrounding estuarine environments.

Salinity and frequency of tidal flooding are the most important factors in determining the types of plant and animal populations that inhabit a particular marsh. Some marshes along the eastern shore and mouth of the Bay are subjected to high levels of salinity. Others are fed with brackish water, while those located in the northern reaches of the Bay and its tributaries are, for the most part, freshwater marshes. Each type offers different amenities and attracts different plant and animal populations.

In general, freshwater marshes have larger and more diversified plant populations. For instance, the overall production of plant material (biomass) in freshwater marshes is estimated to be two to three times greater than that of salt water marshes.

Poised between land and water, marshes absorb the erosive energy of Bay waves and may also act as nutrient buffers, regulating the flow of nutrients into the Bay. Nutrients flow into the marshes from land sources, and from the Bay as a result of tidal action. Once there, the nutrients are trapped and used by marsh grasses. They are gradually released into the Bay during decomposition of the grasses.

Because of their bountiful supply of nutrients, marshes are extremely productive. In fact, they are comparable to fertile agricultural lands. This leads to a large quantity of plant biomass. There is a huge amount of visible plant material in marshes. However, this just constitutes above-ground biomass. The below-ground biomass composed of root and rhizome material is often more than double the above-ground biomass. This adds up to a tremendous reservoir of nutrients and chemicals bound up in plant tissue and sediments.

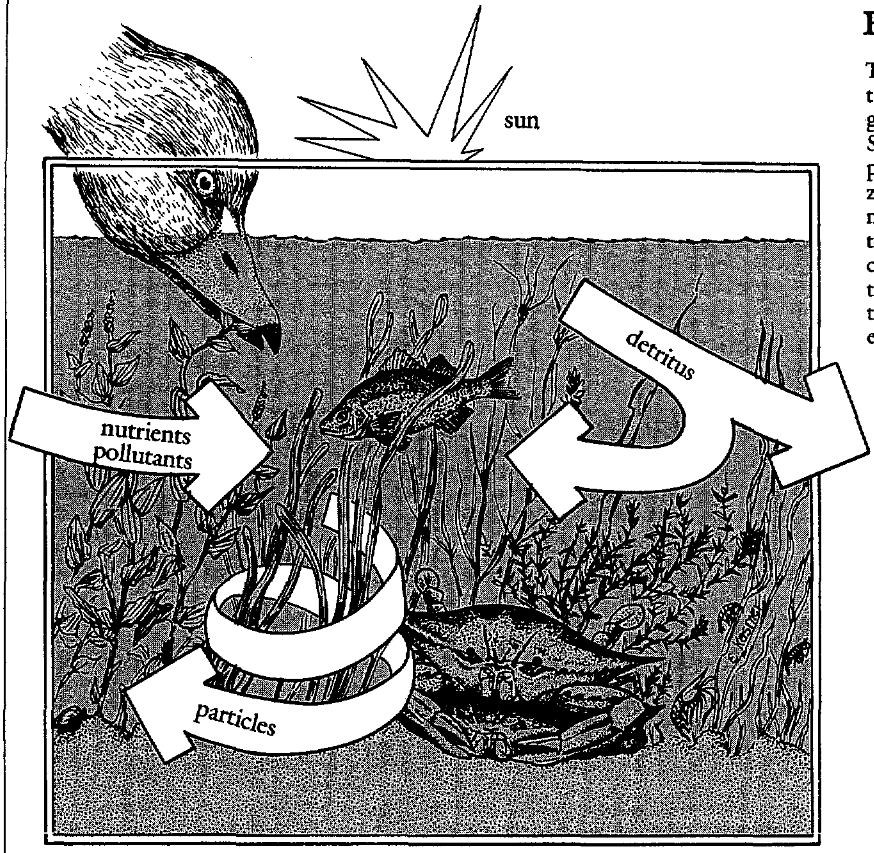
Plant life varies according to salinity. Freshwater marshes include cattails, reeds, arrow-arum, big cordgrass, wild rice, three-square, tearthumb and pickeral weed. The coastal salt marshes of the mid and lower Bay are dominated by salt meadow cordgrass, saltgrass and saltmarsh cordgrass. Finally, the irregularly flooded salt marshes possess the fewest species of plants and are dominated by needlerush.

The abundance of food and shelter provided by the marsh grasses ensure a very favorable habitat for the other members of this community. A host of intertebrates feed on decomposed plant material and, in turn, provide food for numerous species of higher animals. Another source of food is the dense layer of microscopic animals, bacteria and algae that coats the stems of marsh plants. However, decomposing plants and, to a lesser extent, dead animals provide the major food for the marsh dwellers. Therefore, the primary food web in the marsh environment is based on detritus (dead organic matter).

Bay Grass Communities

Approximately ten species of bay grasses occur in the Chesapeake. They are often referred to as Submerged Aquatic Vegetation or SAV. Most of the grasses cannot withstand extensive drying and live with their leaves at or below the surface of the water. Light penetration determines the depths to which bay grasses live. The water surrounding the grasses can contain substances that block or scatter the transmission of light so that, in relatively clear waters, bay grasses can exist in water depths up to about 10 feet.

Like the marsh grasses, the various species of submerged grasses are distributed according to salinity. The substrate to which the roots of bay grasses attach also affects their distribution. They thrive best in relatively fine sediments, but can tolerate some organic matter or fine sand. Turbulence caused by wave action can also restrict their distribution. Although submerged grasses can act as "baffles" to reduce



Bay Grass Community

This community typically contains a seasonally abundant group of plants and animals. Shelter, food and nutrient processing (such as remineralization of organically-bound nutrients) are important characteristics. There is a dynamic exchange of materials between the bay grass community and the surrounding estuarine environment.

wave energy and slow water velocities, highly exposed locations create so much water movement that the grasses cannot survive.

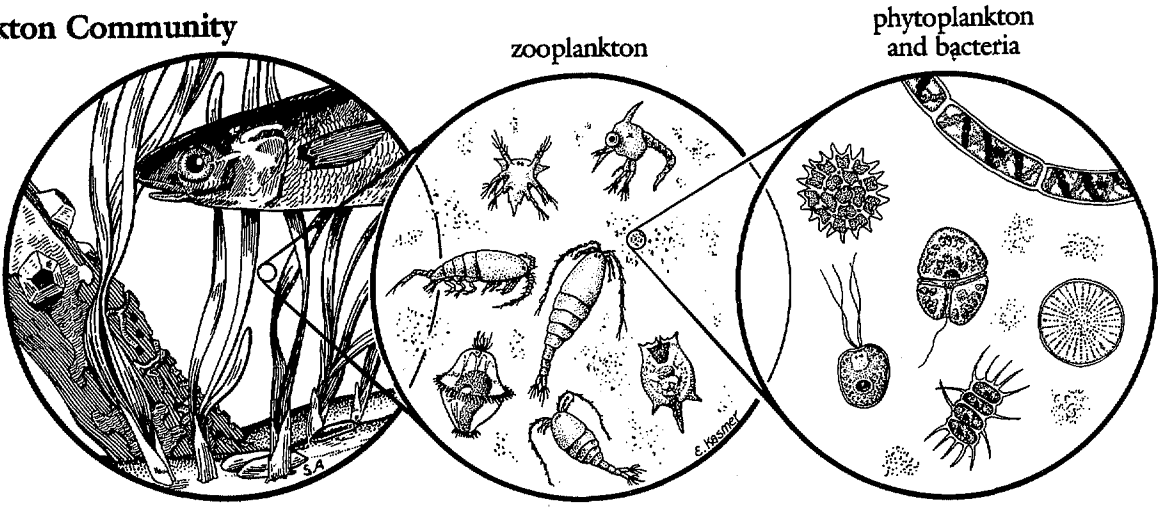
The chemistry of their surrounding water is critical to the survival of submerged grasses. Toxic materials such as herbicides or heavy metals can so disrupt the physiology of the plants that they die. On the other hand, enough needed materials like nutrients must be present in the sediment pore water for survival. Excessive nutrient enrichment may compromise the existence of submerged grasses by favoring the growth of phytoplankton and epiphytes (fouling plant growth) which in turn block out light available to grasses.

Submerged grasses are an important link in the food chain of the Bay's waters. These grasses provide protective cover and food for a diverse community of organisms which share this zone. Epiphytic plants use them as a place to attach. They provide support for the larval stages of small marine snails as well as a variety of other invertebrates which feed on the decaying grasses. In turn, many of the invertebrates provide food for small blue crabs, striped bass, perch and other fish. Ducks and geese also feed on the bay grasses and other small inhabitants of this community. Wading birds such as herons often feed on small fish in this area.

Another important ecological function of bay grasses is their ability to slow down water velocities, causing particulate matter to settle at the base of their stems. Water thus tends to be more clear near grass beds. Finally, like marsh grasses, bay grasses can act as nutrient buffers, taking up nitrogen and phosphorus and releasing them later when the plants decay.

Surveys of bay grasses have revealed a serious decline in populations throughout the Bay. Previously, fluctuations in abundance of certain species, such as eelgrass (reduced in 1930's) and Eurasian milfoil

Plankton Community



(abundant growth, then reduction in the 1960's) have occurred, but the current situation may be a cause for concern because it is so geographically widespread and involves all species.

Plankton

The plankton form another important and representative community in the Chesapeake. This predominantly microscopic community includes phytoplankton, zooplankton and bacteria. These organisms exist largely at the mercy of the current and tides, floating and drifting with the water's movements. Some of the tiny creatures, however, have been shown to move up or down in the water to take advantage of light or to drop below the halocline to avoid being washed out to sea.

Phytoplankton are tiny one-celled plants often occurring in colonies known also as algae. Although there are numerous varieties, the major types found in the Bay are diatoms, dinoflagellates, golden algae, green algae, and blue-green algae. Some phytoplankton, called nannoplankton, are extremely small. What they lack in size, however, the nannoplankton make up for in numbers. They are responsible for as much as two-thirds of the phytoplankton tissue produced in the Bay.

Like all plants, phytoplankton require light to live and to reproduce. Therefore, the largest colonies are found near the surface. Salinity is another important factor in determining phytoplankton distribution. The largest number of species are found in the more saline waters at the mouth of the Bay. Weather is also a major determinant in the life of these plants. The greatest concentrations occur in the late summer or fall, when the days are long and the water is warm. However, during some years the lower Bay shows a spring pulse (bloom), with large numbers of phytoplankton in evidence. These high concentrations of phytoplankton produce the characteristic green color of estuarine and near-shore waters. Under certain conditions, phytoplankton with red or brown pigments will dominate the water, producing a red-tinted bloom, sometimes referred to as "red tide."

Because phytoplankton reproduce quickly, changes in chemical conditions, such as addition of nutrients, may cause rapid changes in the number and diversity of species. Such changes may result in the presence of a single species, like the type causing "red tides." These blooms can have serious consequences. Once they begin to decay, decomposing organisms can completely deplete all dissolved oxygen reserved, suffocating other estuarine animals.

Phytoplankton are the major food source for microscopic animals called zooplankton. Most zooplankton are copepods, a particular type of crustacean that is only about a millimeter long. One study found three million in a single cubic meter of water. Their distribution is related to salinity levels and matches that of their favorite meal, the phytoplankton. Copepods also feed on plant matter and bacteria.

The tiny larvae of benthic animals and fish are also considered to be zooplankton, although they remain so only temporarily. These larvae may be consumed by larger animals, and may themselves, as they grow, consume copepods.

The final group of zooplankton found in the Bay are the protozoa. These single-cell creatures feed on detritus and bacteria. They, in turn, become food for larvae, copepods and larger protozoa.

Bacteria have an important function in the Bay. They are essentially the undertakers or decomposers. Their primary function is to break down dead matter, particularly plants. They feed on the detritus and are then eaten by zooplankton and so on up the food chain. This process makes the nutrients in dead plant and animal matter available for consumption by larger organisms.

Bacteria are either normal residents of the Bay or can be introduced through various pathways including human sewage and precipitation runoff from the land. The variety that specializes in feeding on human waste are called coliform bacteria. Coliforms in themselves are not normally harmful. They are, however, an indicator that pathogens (disease-producing bacteria) may be present. More coliforms are likely to be found near large population centers.

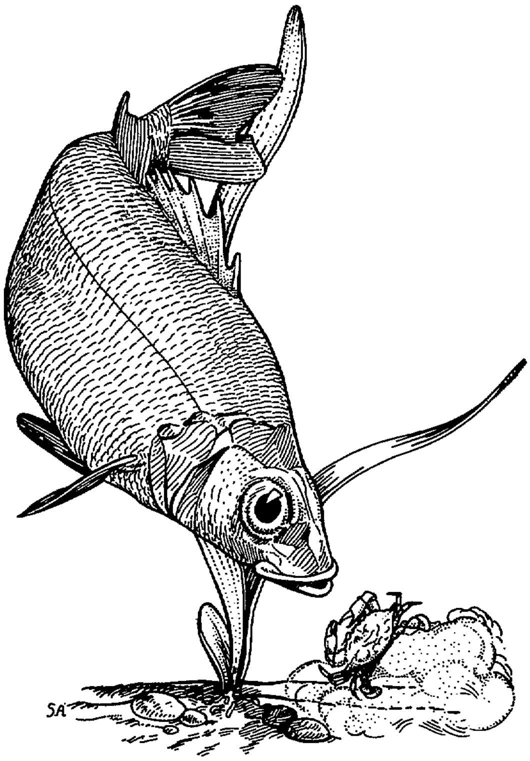
A final group of plankton dwellers is clearly visible to the unaided eye. These are the jellyfish, sea nettles and comb-jellies (ctenophores) which move with the water currents.

Life at the Bottom

The organisms that live on and in the bottom of the Bay form a complex assemblage of communities. Commonly termed benthos, they are considered in terms of the animal components. However, the plant and bacterial constituents should not be overlooked. The roots and lower portions of submerged aquatic vegetation supply physical support for a wide variety of "epibiotic" organisms. An oyster bar that supports many small organisms is an example of a benthic community. Benthic communities also exist on bare, unvegetated sediments, but numbers may be more limited because there is less protection against predators.

Salinity and sediment type are the two major determinants to the distribution of benthos. These two factors result in a gradient of benthic organisms within the Chesapeake. With respect to sediments, neither coarse sands nor soft, slurry muds usually possess rich or diverse benthic populations. Sediments containing a significant amount of silts and clays are considered optimum.

Prefixes are useful to differentiate the various types of benthic organisms. Epifauna, dwelling upon the surface, are distinct from infauna, which form their own community structure under the sediment surface. Other prefixes categorize benthic organisms by size. For example, mega- or macro-fauna are the largest, most visible animals, while meio- and micro-fauna range downward in size.



The benthic community has an important effect on the physical and chemical condition of the sediments, especially the upper eight to ten inches. Filter feeders, such as oysters and clams, pump large volumes of water through their bodies and extract food from it. Infaunal deposit feeders, such as worms, plough through the sediments in search of food. Predators such as the blue crab scurry across the sediment surface. These activities all help to keep the sediments stirred up, increasing the rate of diffusion, or exchange, of materials into the water and facilitating the passage of oxygen into the sediments.

Benthic animals also affect the structure of the sediments. Some build tubes or burrows through which they pump water. Many benthic animals bind sediments together in fecal pellets which settle more readily. If toxic chemicals are present in the sediments, they can be taken up by benthic fauna, and in some cases harm them.

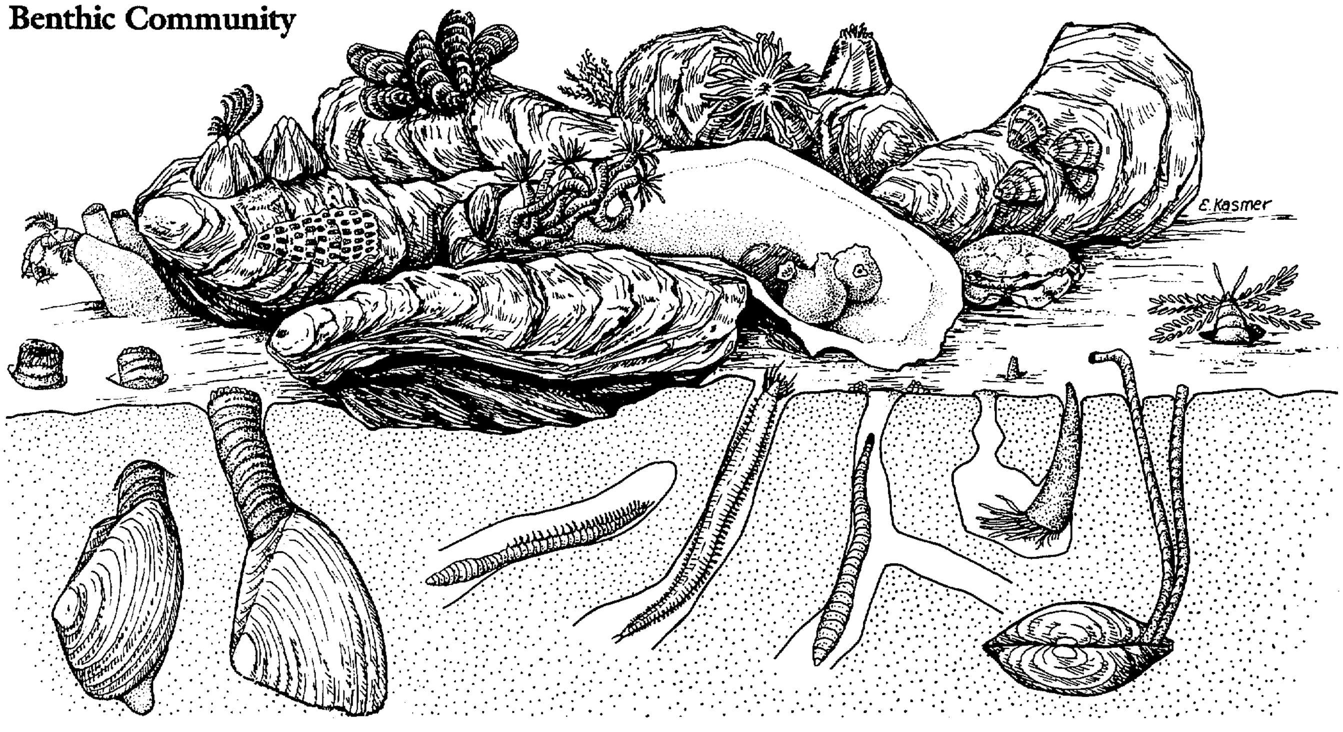
Some commercially valuable benthic organisms, such as oysters and blue crabs, are widely distributed. Others are more limited by salinity. For example, hard-shell clams require highly saline (greater than 15 ppt) waters, while soft-shell clams can thrive in lower salinity levels. Less commercially important benthic species include barnacles and sponges, which live in higher salinities; mysid shrimp and mud crabs in mid-salinity ranges; and brackish water clams in lower salinities. Intolerance to lower salinities can also limit the distribution of certain benthic predators, parasites and diseases. Oyster drills, which feed on oysters, are far less of a problem in upper Bay waters than they are in the lower Bay because of their intolerance to low salinities.

The Swimmers

Nekton are the swimmers of the Bay. They control and direct their movements, and thus their own distribution, throughout the Bay. This group includes fish, certain crustaceans, squid and other invertebrates.

Approximately 200 species of fish live in the Chesapeake. They can be divided into permanent residents and migratory fish. The residents tend to be smaller in size, therefore less capable of negotiating the distances often covered by the larger migratory species.

Benthic Community



Smaller resident species include killifishes, anchovies, silversides, hogchokers and gobies. They are normally found in shallow water where submerged vegetation provides cover. Here they feed on a variety of invertebrates such as zooplankton and amphipods. Larger residents also tend to make their home in these areas, feeding on the invertebrates and the smaller resident fish.

The migratory fish generally fall into two categories: those who spawn in the Bay or its tributaries, and those who spawn on the ocean shelf. The members of the Bay spawning category migrate varying distances to spawn in fresh water. This group includes a few species that really could be considered Bay residents. For instance, during the spawning season, yellow and white perch travel relatively short distances from their residence areas in the brackish water of the Bay to freshwater areas in the upper Chesapeake. Striped bass also spawn in the low salinity areas of the Bay. Some remain in the Chesapeake to feed, while others migrate to the ocean waters. Shad and herring are truly migratory, traveling from the ocean to fresh water to spawn and returning to the ocean to feed.

Other migratory fish spawn on the ocean shelf and use the Bay strictly for feeding. Some journey into the Bay while still in the larval stage and use the shallow waters of the Bay as a nursery. Croakers, drum, menhaden, weakfish and spot fall into this group. The menhaden deserve special note. They occupy the Bay in such abundance that they support a major commercial fishing enterprise. The adults of this category feed on the abundant supply of phytoplankton. Bluefish only enter the Bay as young adults or mature fish.

One species that must be considered a migratory fish because of spawning practices is the eel. Eels reside in the Bay for long periods, but eventually migrate to their ocean spawning grounds in the Sargasso Sea.

Other organisms appearing in the nektonic food web are some of the "lesser" members of the nekton mentioned earlier. Swimming crustaceans include shrimp, which spend most of their adult life near the bottom. Usually thought of as a "creeper," the blue crab has developed a swimming capacity with one pair of powerful legs that enable it to travel considerable distances in the Bay. Finally, numerous members of the shark family enter the Bay as do several marine mammals including the porpoise.

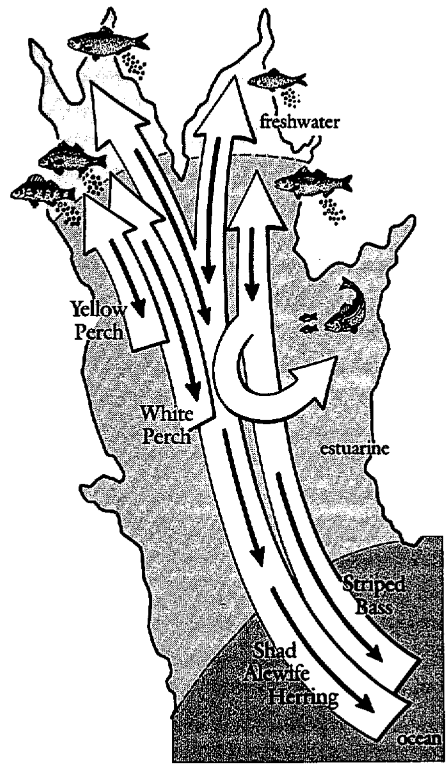
Ecological Succession

The replacement of one Bay species in a community by another is a natural and usually long-term process. This process is called ecological succession, and the rate of succession depends on the type of community. In the Bay the rate may not be constant because of the powerful influence of physical factors affecting distribution and abundance of species. Where sediments accumulate quickly, replacement of open water plankton and fish by marsh, and finally by terrestrial communities, will eventually occur.

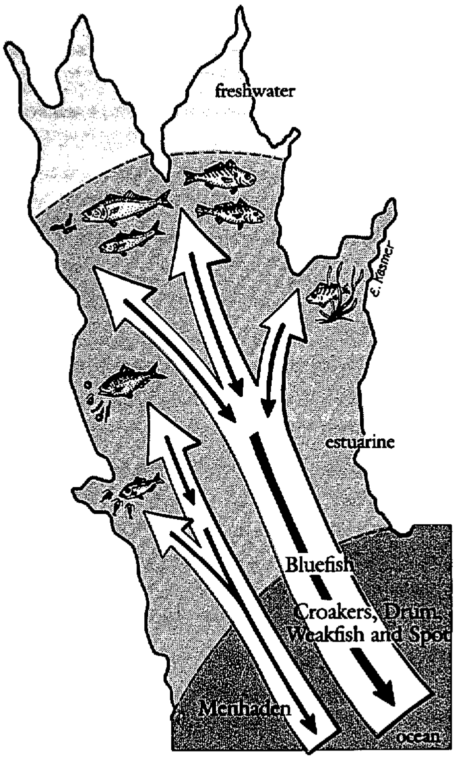
Ecological recovery, which has some features in common with ecological succession, also occurs on newly formed bottom deposits. Such deposits can result from dumping of wastes. Natural causes, such as hurricanes, can damage bottom communities through increased sedimentation and associated low levels of dissolved oxygen. If the environment is altered by humans, say by introducing an excessive supply of nutrients to Bay waters, then the combinations of species in the Bay communities will shift in favor of those which can better utilize these nutrients.

Migratory Pathways of Fish

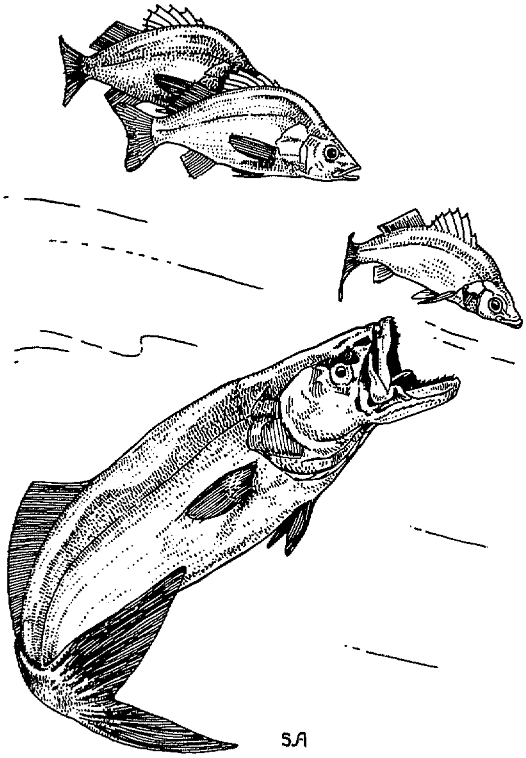
Spawning



Non-Spawning



Food Production & Consumption



Members of the Bay ecosystem are related to each other in many ways. Perhaps the most important relationship among Bay species is their dependence upon each other as a food. All biological material ultimately serves as food for some organism in an ecosystem food web (a term used to describe the relationships between food production and consumption). The process of obtaining and using food is, to a great extent, a process for transferring different compounds containing the key element carbon.

We are all carbon-based creatures. It is the basic element in all life-giving organic nutrients such as proteins, carbohydrates, fats and nucleic acids.

The processes by which organisms acquire, utilize and ultimately lose this important element form the basis of the Chesapeake's life support system. All the complex processes and interactions involved in this system are essentially part of a transfer cycle in which sunlight, carbon and oxygen play major roles.

Plants and some bacteria have the ability to produce their own food by combining carbon dioxide and water into high-energy organic compounds (usually sugar) through photosynthesis, using energy from the sun. These organic compounds form the plant's cellular structure, permitting growth to occur. Because of this ability to use inorganic carbon dioxide to produce their own food, plants are referred to as autotrophs—self feeders. Autotrophs are the only organisms able to produce new food from carbon dioxide, water and light energy, and are the ultimate producers of all food on the earth; all other organisms must feed directly or indirectly on organic material produced by autotrophs.

Animals don't have the ability to photosynthesize inorganic carbon. Instead, they acquire carbon in its organic form by ingesting the organic matter contained in plant and animal tissue. The animal then breaks this organic material down into components from which to derive energy and the material needed for action and growth. Thus animals, including protozoa, fungi and most bacteria are heterotrophs, or other-feeders. To grow they must obtain their food from already existing organic material. This organic substance may be in the form of plants, other heterotrophs, or dissolved in water.

Whether they produce them themselves (autotrophs) or ingest them from other sources (heterotrophs), all organisms must break down organic molecules to use the carbon and energy contained therein. This process is called respiration. Every life-supporting activity (growth, heartbeat, swimming) requires energy. This energy comes from respiration. Respiration requires oxygen, and during this process organic carbon is given off as carbon dioxide.

Respiration and photosynthesis are complementary, and comprise the carbon-oxygen cycle. Plants release more oxygen than they consume, while animals use that excess oxygen for respiration. In turn, animals release carbon dioxide, which plants require.

This basic system indicates that each organism supplies the others with the requisites of life. Most biological material ultimately serves as food for some organism and, through this process, biological molecules and their inorganic constituents are continuously cycled through the ecosystem. Although this carbon/oxygen cycling system appears simple, its application in the Chesapeake ecosystem incorporates an array of complex interrelationships and dependencies.

While carbon and oxygen are the most prevalent elements in our physical make-up, many others play important roles in the creation, growth and functions of organisms. Nitrogen and phosphorus are two such elements. They are crucial to the operation of the Bay's life support system.

Nitrogen is a major component of all organisms, primarily as a key ingredient in protein. When an organism dies, bacteria and fungi break the protein down into amino acids. Bacteria then remove the carbon, converting the acids into ammonia. Plants are able to use this ammonia as a source of nitrogen. In the presence of oxygen, other bacteria can convert the ammonia to nitrite and nitrate, which are also good nitrogen sources for plant life. However, under low dissolved oxygen conditions the bacteria reduce nitrate to elemental nitrogen which, as a dissolved gas, is not available to most aquatic organisms. In tidal freshwater, some blue-green algae are able to use elemental/gaseous nitrogen directly and, thus, have no requirements for combined nitrogen.

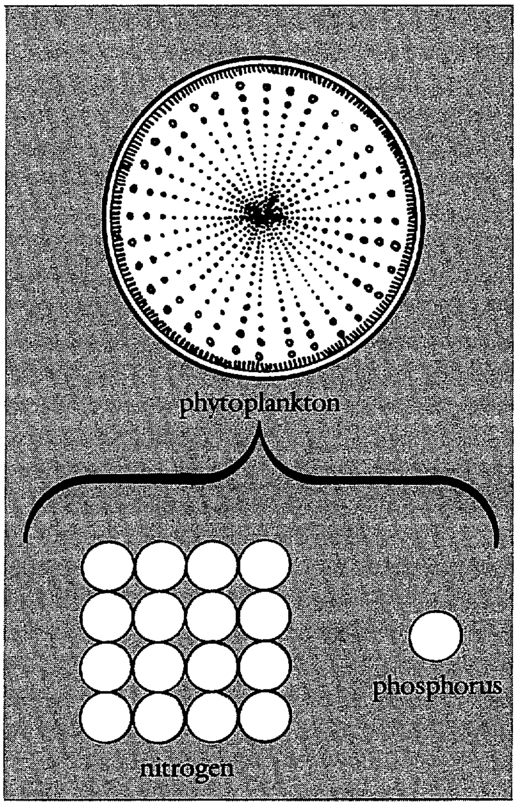
Phosphorus is another element essential to plant growth. Decomposing plants and animals yield organic phosphorus. During the decomposition process, bacteria convert this organic phosphorus to phosphate when oxygen is present. In this form, it is readily employed by plants. However, phosphate settles out of water very quickly, sometimes resulting in situations where sufficient quantities are not available to assure adequate plant growth.

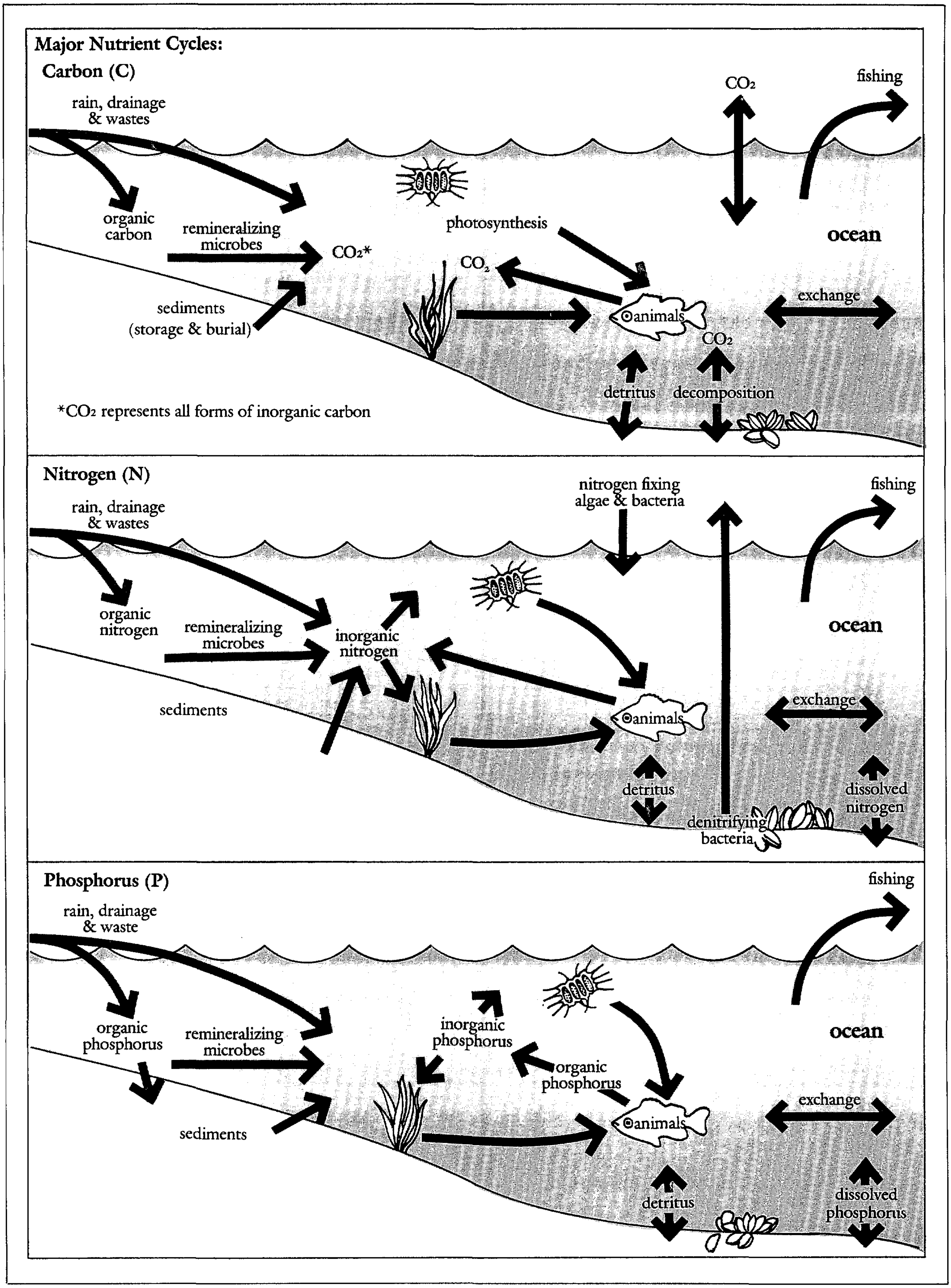
Temperature plus the overall availability of sunlight and carbon dioxide, along with usable nitrogen and phosphorus, control the rate of photosynthesis in the Bay. Since plants are the only organisms capable of producing "new" food from inorganic matter, the rate of photosynthesis largely determines the production of organic carbon (biomass) and thus the ultimate availability of food in the Chesapeake.

To illustrate how these factors affect the productivity of the Bay, let's look at the Chesapeake's most copious food producer, the phytoplankton. Like all plants, phytoplankton require sunlight, nutrients and water. In the Bay, water is never a limiting factor. However, the others may limit potential phytoplankton growth. The amount of sunlight available to an aquatic plant depends on factors such as cloudiness, the sun's latitude, choppiness of the water, turbidity and depth. Temperature is another factor which can reduce the rate of photosynthesis.

Nutrients in the form of carbon dioxide, usable nitrogen and usable phosphorus must also be available in the proper proportions. Studies have established that phytoplankton, the Chesapeake's most copious food producer, require an approximate carbon:nitrogen:phosphorus ratio of 106:16:1. These nutrients are rarely available in the exact ratio that is required. Normally, one nutrient is in short supply compared to the others. That one is referred to as the "limiting nutrient." If it is added to the water, a growth spurt may occur in one or more species. Conversely, if its availability is further reduced, a decline in plant production will occur. Additional increases in the non-limiting nutrients will not increase production.

Nutrient Mix for Phytoplankton Growth




Major Nutrient Cycles:

The role of these limiting factors on food production in the Chesapeake and its tributaries is currently being studied. Some evidence suggests phosphorus may control the growth of some phytoplankton species in the spring, especially in the tidal freshwater and brackish areas. Nitrogen may be a limiting factor at higher salinities, particularly during warm months. Carbon dioxide limitations may control the rate of further photosynthesis during algae blooms. Sunlight and possibly temperature determines the rate of photosynthesis during the colder months. Turbidity also plays an important role in affecting the quality and quantity of light that reaches the plant.

Normally, organic carbon (or biomass) production and decomposition keep pace with one another over an annual cycle, causing the total amount of biomass in an ecosystem to remain fairly constant. However, biomass production at all trophic levels is ultimately dependent on the production of new food by plants (autotrophs). This production is, in turn, linked to the availability of sunlight and nutrients. Sunlight availability depends largely on weather conditions. Nutrient availability depends on the carbon, nitrogen and phosphorus cycles, which are extremely complex and very sensitive to changes caused by pollutants. Since substantial quantities of nutrients are washed into the Bay from its tributaries, they also have a significant effect on the overall nutrient availability within the Bay proper.

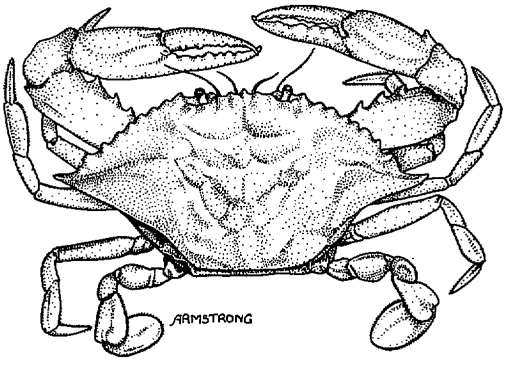
As you can see, the Bay's entire life support system is balanced on some rather complex underpinnings. Even though the Chesapeake's production capacity is massive, it is also finite. A look at the Bay's food web should provide an understanding of how food production problems at even the lowest and most broadly based trophic level can have dramatic effects on higher trophic levels.

The Food Web

The Chesapeake is noted for its ability to produce food. However, the production of economically important foods like fish and shellfish depends on the production of plant biomass in the Bay. The animals, plants and microbes of the Bay are connected by a complex network of feeding interactions called the food web.

The food web has both direct and indirect linkages to higher trophic levels. Typically, the direct food web encompasses four key linkages—five, if we humans are included. For example, a predominant feeding pattern in the open waters of the Bay starts with phytoplankton converting sunlight and nutrients into living tissue. They are, in turn, eaten by copepods, members of the zooplankton family. The copepods are then swallowed by anchovies, which are later eaten by bluefish. This illustrates how the organic carbon originally produced by the plant is passed through successively higher trophic levels. The indirect food web encompasses the feeding on dead organic matter by detritivores.

The amount of energy available decreases at each successively higher trophic level. This is due to the fact that the transfer of energy (required to produce biomass) from one trophic level to the next is inefficient. Several factors account for this. For example, of the total available phytoplankton carbon/energy, only a portion is ingested by zooplankton. Even the portion that is ingested is not fully utilized. Some is not assimilated by the herbivore's digestive system. Another portion of the carbon/energy goes to the maintenance of cellular respiration to provide energy for food collection and locomotion. Only a small fraction is allocated to growth and reproduction. Since



these are the only functions that produce additional tissue, the carbon/energy assigned to them is all that is available to the predator at the next trophic level.

The efficiency of the carbon/energy transfer from one trophic level to the next is approximately 10 percent. This lack of efficiency shows why there is only a limited amount of organic carbon/energy available at the top carnivore level. For example, for every pound of commercial fish taken from the Chesapeake, almost four tons of organic material had to be produced at the plankton trophic level.

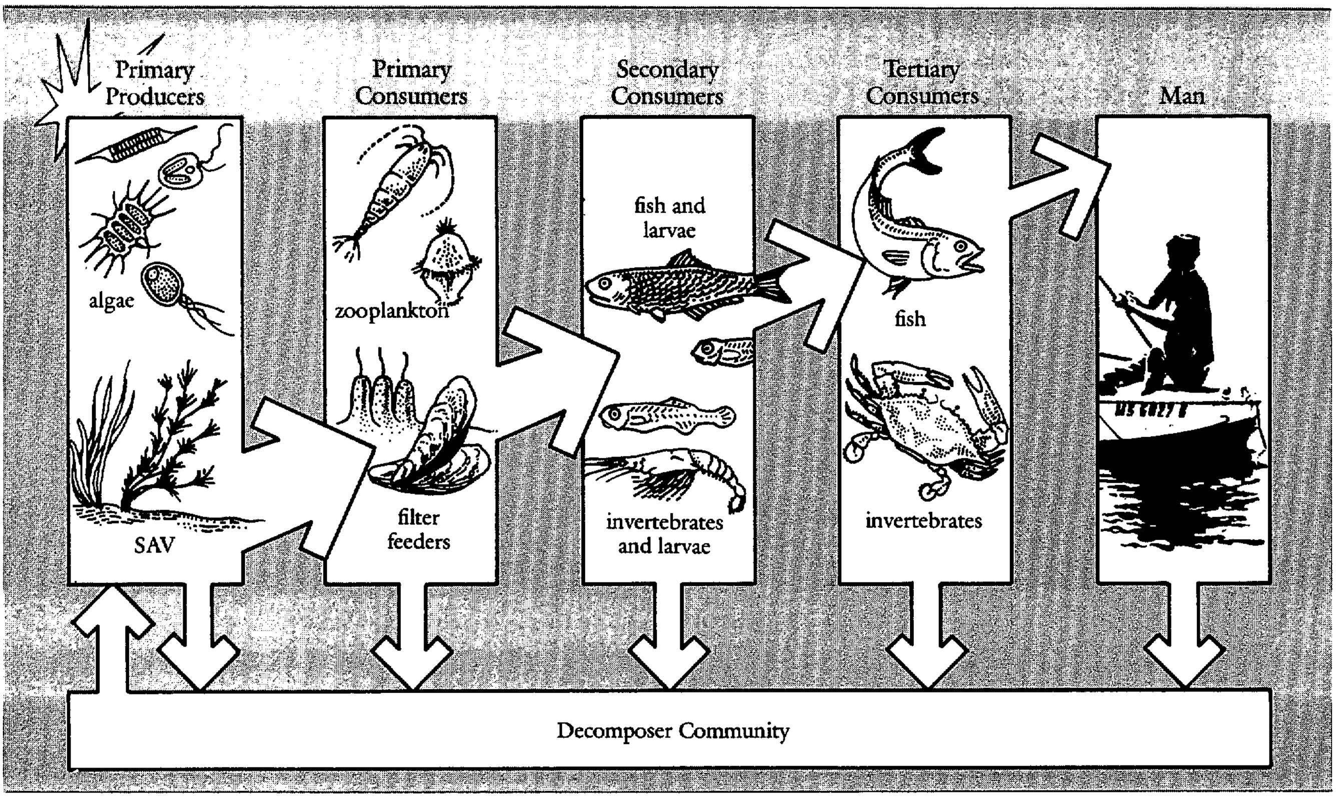
Several important conclusions can be drawn. First, because plants are the source of all food, their rate of biomass formation determines the quantity of animals and all other organisms in the Bay.

Second, through the food web concept we can see that energy flows through an ecosystem. It is provided by the sun and is dissipated at every transfer between trophic levels. (This flow of energy contrasts with the cycling of nutrients, which change in form but are not degraded to heat in every transfer as is true of energy.)

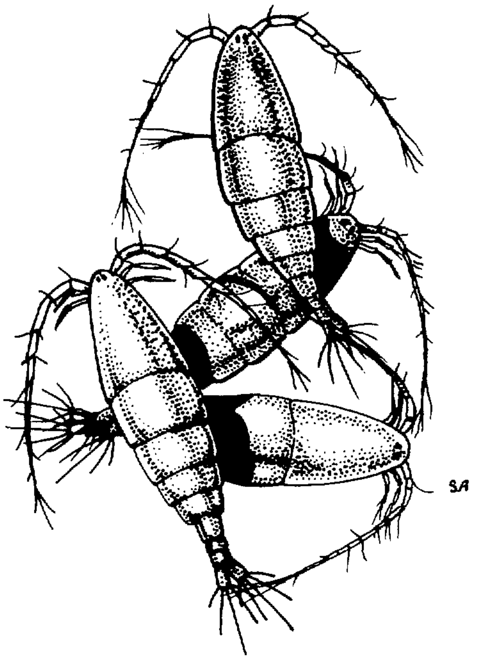
Third, an ecosystem can support relatively few animals at the highest trophic level. In the Chesapeake Bay, massive quantities of plants are required to support relatively few carnivores such as the striped bass or bluefish.

Fourth, because the amount of food energy available decreases with each rise in trophic level, feeding at the lowest trophic level means that more food (energy) is available. Some animals are known to switch from carnivory to herbivory when food becomes scarce. This switch theoretically increases the amount of food available to them five- to tenfold.

The Bay Food Web



Finally, high-level carnivores consume many times their weight in food. If this food contains a toxic chemical, even in small amounts, the fish or animal may be exposed over time to high levels of the chemical. Heavy metals and organic chemicals may be stored in the fatty tissues of the animal and concentrate there. As a result, the body may contain a much higher concentration of the chemical than did its food. This phenomenon is called biological magnification.



Direct & Indirect Food Webs

As mentioned earlier, two basic pathways dominate the estuarine food web. The direct pathway leads from living plants to higher animals. The indirect, or detritus pathway leads from dead organic matter to lower animals then to higher animals. The marsh and bay grass communities are strongly dominated by the detritus pathway.

The importance of the detrital food web has not always been easy to demonstrate experimentally. The higher plants, like eelgrass, saltmarsh, cordgrass and widgeongrass contribute most of their carbon content as detritus. However, the small algae, like diatoms and filamentous green algae that grow as epiphytes on the grasses, are usually eaten by grazers, which puts them in the direct predatory chain.

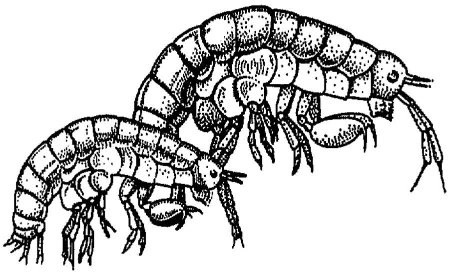
In deeper waters, detritus resulting from dead phytoplankton, . zooplankton and larger animals, as well as that washed in from upland drainage, marsh and bay grass communities, continuously "rains" down on the benthos. Here, bottom-dwelling animals such as oysters, clams, crustaceans, tube worms, shrimp and blue crabs feed on it. These animals then provide food for fish (and people). To the extent that live phytoplankton reach the benthos where filter feeders can directly remove the cells or small colonies from the water, they contribute directly to the benthic food web.

The plankton community is dominated by a direct food web, especially seaward of the turbidity maximum. Relatively little is known about the importance of individual phytoplankton species in the food web. This is partially due to their great variability from season to season and varied distribution within the Bay. The role of zooplankton is better defined. Knowledge of specific details pertaining to food web relations involving bacteria and other microbes and protozoa is severely limited.

Phytoplankton are divided by size. The larger species are often called "net" plankton, because they are traditionally collected with fine nets. Many diatoms and large dinoflagellates are in this group. Species that pass through fine nets are known as nannoplankton. The nannoplankton are believed to be very important as food, and may contribute from 50 to 75 percent of the primary organic carbon production attributed to phytoplankton. Microzooplankton, including rotifers and tintinids (a group of protozoa), are probably the major consumers of nannoplankton. "Net" phytoplankton provide food for larger zooplankton and some fish. Bacteria, fungi, phytoplankton, and possibly small protozoa provide food for oysters and clams. In addition, all plankton contribute to detritus.

Copepods, the dominant form among zooplankton, are a key link in the food web between phytoplankton and larger animals. Larger copepods feed on most phytoplankton species and occasionally on the juvenile stages of smaller copepods. Small copepods concentrate on the smaller members of the phytoplankton species.

Copepods often fill the waters of the Bay, devouring enormous quantities of phytoplankton. Most production of animal protein from



plant materials in marine waters is carried out by copepods. On a larger scale, copepods are the world's largest stock of living animal protein. Larger carnivores feed voraciously on copepods. One herring, for example, may consume thousands of the tiny creatures in a single day.

Most of the Bay's fish are part of the direct food web but their feeding habits are complex. Some Bay experts contend that menhaden are the dominant fish in the Bay as far as food consumption is concerned. As juveniles they consume large quantities of zooplankton. Upon reaching adulthood, they switch to phytoplankton. The gill rakers of the adult are extremely fine and act as a filtering net. Adult menhaden swim with their mouths open and "sample" the plankton that appear in their paths. Menhaden are a major food of striped bass and bluefish. They also support a large commercial fishery that incorporates them into poultry and animal feed.

Like menhaden, anchovies and all fish larvae are primarily plankton feeders. Adult striped bass, bluefish and weakfish (sea trout) feed mainly on other fish. Striped bass and other predators may feed upon their own young, thus contributing to this species' periodic population growth/reduction cycles. Finally, there is a large group of fish that are omnivorous, such as eels and croakers. Their diets are often composed of planktonic copepods, amphipods, crabs, shrimp, small bivalves and small forage fish. Small forage fish, like killifish and silversides, often feed upon the epifauna and epiphytes of the marsh and littoral communities.

Some fish may be "specialty" feeders, but most species subsist on a variety of prey, or have alternative foods. This ability to switch from an item in low abundance to a more available food contributes to the overall stability of the fish community by assuring long-term survivability and providing a buffer against major changes.

Why is the Chesapeake Bay So Productive?

The physical and ecological processes of the Bay make it possible for us to understand why the Bay is such a tremendous food source.

The Bay sustains several juxtaposed habitats, which exchange materials and complement one another's resources. For example, detritus (dead organic matter) derived from marsh and bay grass communities is a major source of food for benthic animals. On the other hand, nutrient-laden sediments from the Bay's waters are deposited in marshes, increasing productivity there.

The existence of two major food webs, the detrital (indirect) pathway and the predatory (direct) pathway, promotes overall stability. If one pathway falters, resources can be used via the other. Some organisms can even switch food sources.

The estuarine circulation patterns result in accumulation and retention of suspended sediments and nutrients. This yields the Bay's high productivity. The sediments and nutrients that accumulate in the zones of maximum turbidity result in increased phytoplankton growth, although the turbidity itself can limit growth by blocking out light. Detritus is also retained in the estuary because of the Bay's circulation. This longer retention increases its availability to animals. It also permits complete decomposition by microbes, providing a source of inorganic nutrients for plants.

This brief look at the Bay's life support system should convey some idea of its true complexity. Even the smallest of creatures plays a vital role in the overall success of this system. The dual food webs provide a modicum of resilience, but by no means guarantee continued levels of high productivity.

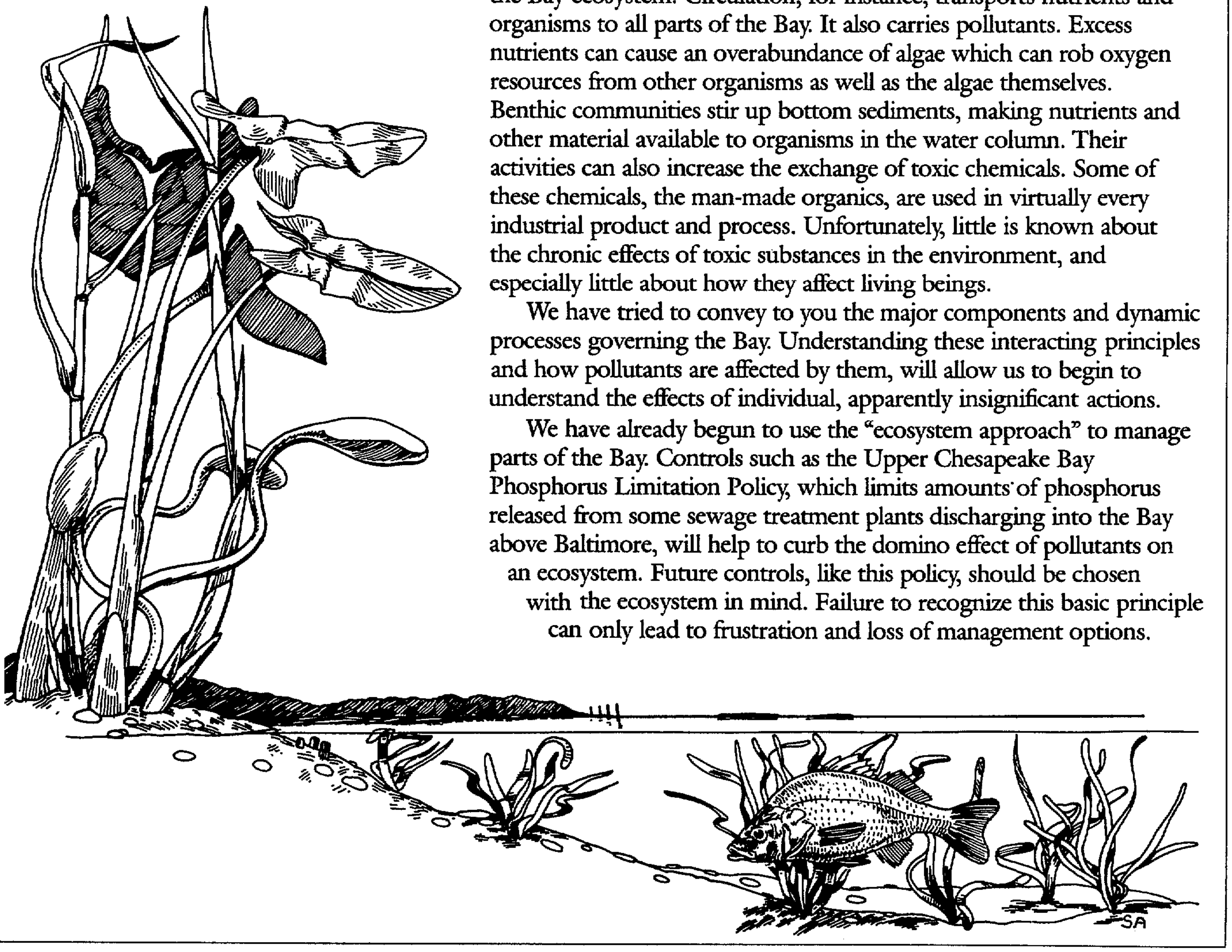
The Future

Thus far, the Bay and tidal tributaries have absorbed considerable pressure from both natural and human causes. They have remained highly productive. But we cannot count on this natural carrying capacity to endure any and all future pressures. In recent years, the Bay has been showing signs of wear and tear. Sewage and land run-off have markedly altered the nutrient balance of some of the Bay's tributaries and possibly of the upper Bay itself. Carbon, nitrogen and phosphorus loadings have increased and, more importantly, the ratios of one material to another have changed. The results of some of these changes are obvious — for example, the pea green blankets of algae and the decline in submerged aquatic vegetation.

Other effects are not as obvious. They may show up over time, gradually becoming apparent among the processes taking place within the Bay ecosystem. Circulation, for instance, transports nutrients and organisms to all parts of the Bay. It also carries pollutants. Excess nutrients can cause an overabundance of algae which can rob oxygen resources from other organisms as well as the algae themselves. Benthic communities stir up bottom sediments, making nutrients and other material available to organisms in the water column. Their activities can also increase the exchange of toxic chemicals. Some of these chemicals, the man-made organics, are used in virtually every industrial product and process. Unfortunately, little is known about the chronic effects of toxic substances in the environment, and especially little about how they affect living beings.

We have tried to convey to you the major components and dynamic processes governing the Bay. Understanding these interacting principles and how pollutants are affected by them, will allow us to begin to understand the effects of individual, apparently insignificant actions.

We have already begun to use the "ecosystem approach" to manage parts of the Bay. Controls such as the Upper Chesapeake Bay Phosphorus Limitation Policy, which limits amounts of phosphorus released from some sewage treatment plants discharging into the Bay above Baltimore, will help to curb the domino effect of pollutants on an ecosystem. Future controls, like this policy, should be chosen with the ecosystem in mind. Failure to recognize this basic principle can only lead to frustration and loss of management options.



Technical Reviewers:

Scott W. Nixon
Richard L. Wetzel
Walter R. Boynton
Robert B. Biggs
David A. Flemer
Willa C. Nehlsen
C. John Klein
Bert S. Brun