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Salt and Fresh Water Estuaries

What is an Estuary?

An estuary is a partially enclosed body of water, and its surrounding coastal habitats, where saltwater from the ocean mixes with fresh water from rivers or streams. In fresh water the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of seawater and fresh water in estuaries is called brackish water and its salinity can range from 0.5 to 35 ppt. The salinity of estuarine water varies from estuary to estuary, and can change from one day to the next depending on the tides, weather, or other factors (Levinton, 1995.)

Estuaries are transitional areas that straddle the land and the sea, as well as freshwater and saltwater habitats. The daily tides (the regular rise and fall of the sea's surface) are a major influence on many of these dynamic environments. Most areas of the Earth experience two high and two low tides each day. Some areas, like the Gulf of Mexico, have only one high and one low tide each day. The tidal pattern in an estuary depends on its geographic location, the shape of the coastline and ocean floor, the depth of the water, local winds, and any restrictions to water flow. For example, tides at the end of a long, narrow inlet might be amplified because a large volume of water is being forced into a very small space. However, the tides in wetlands composed of broad mud flats might appear to be rather small. With the variety of conditions across the Earth, each estuary displays a tidal pattern unique to its location (Niesen 1982).

While strongly affected by tides and tidal cycles, many estuaries are protected from the full force of ocean waves, winds, and storms by reefs, barrier islands, or fingers of land, mud, or sand that surround them. The characteristics of each estuary depend upon the local climate, freshwater input, tidal patterns, and currents. Truly, no two estuaries are the same. Yet they are typically classified based on two characteristics: their geology and how saltwater and fresh water mix and circulate in them.

However, not all estuaries contain brackish waters. There are a small number of ecosystems classified as freshwater estuaries. These estuaries occur where massive freshwater systems, such as the Great Lakes in the United States, are diluted by river or stream waters draining from adjacent lands.

Estuaries are important natural places. They provide goods and services that are economically and ecologically indispensable. Often called nurseries of the sea (USEPA, 1993), estuaries provide vital nesting and feeding habitats for many aquatic plants and animals. Most fish and shellfish eaten in the United States, including salmon, herring, and oysters, complete at least part of their life cycles in estuaries. Estuaries also help to maintain healthy ocean environments. They filter out sediments and pollutants from rivers and streams before they flow into the oceans, providing cleaner waters for marine life. (NOAA)

How are Estuaries Connected to My Life?

Estuaries are important parts of our lives; interconnected to our economy, hobbies and culture, and an important part of our coastal and ocean ecosystems.

- Estuaries provide commercial economic benefit to the U.S. in the form of seafood sales and jobs.

- Recreational activities – such as fishing, birding, boating and hiking – are enjoyed by millions of Americans each year in estuaries bringing income to coastal communities.
- Estuaries offer cultural importance to Americans. They are often city and trade centers, they are an important source of food, they buffer communities from storm surges, and they have a long history of cultural use by Native Americans.
- Estuaries are vital ecosystems providing diverse habitat and nursery areas for many important organisms.

Because we are all connected to the nation's coasts, our activities have many affects on estuaries, many of which are negative.

- Anthropogenic disturbances to estuaries include coastal development, introduction of invasive species, pollution via runoff, over fishing, dredging and filling, dams, and global climate change.
- From government agencies and laws – established to protect estuaries – to volunteer citizens groups, our coasts are protected, restored and conserved in many ways.
- There are many things you can do around your home and in your community to keep estuaries clean.

Estuaries are Vital to Humans

Estuaries are important parts of our lives. Whether you live near the coast or many, many miles inland, you need estuaries and your actions affect estuaries. Estuaries are interconnected to our economy, hobbies and culture. Estuaries are a vital part of our coastal and ocean ecosystems.

Commercial Economic Benefits

Estuaries provide commercial economic benefits to the U.S. in the form of seafood sales and jobs.

Fancy steamed shrimp or fried catfish for dinner? Chances are they were caught in an estuary. Estuaries provide many benefits to you and your loved ones, whether you live on the coast or in an inland state.

In 2006, the U.S. exported over $3.9 billion in seafood. Estuaries provide habitat for over 75% of the U.S. commercial sea catch. Without estuaries, the trade of seafood, which is so vital to the U.S. economy, would not exist.

Estuaries support jobs and income for many Americans each year. Think about all those who make their money from commercial activities in estuaries. Shrimp trawlers, crabbers and other commercial fishing boats fish in and near estuaries. The seafood they bring in is processed and distributed fresh or frozen by trains, boats, airplanes and trucks across the U.S. and the world. Approximately 85,000 people in the U.S. were employed in the seafood processing and wholesaling sectors in 1999.

There is also commercial value in some other, unexpected estuarine organisms. For example, oysters and clams can be crushed and used as fertilizer. Also, an extract of the horseshoe crab's blood is used by the pharmaceutical industries to ensure that their products (such as intravenous drugs and vaccines) are free of bacterial contamination.

Recreational Benefits

Recreational fishing in estuaries by small boat anglers is hugely popular in the U.S. Also, many Americans also enjoy bird-watching, boating, visiting the beach, sight seeing, botanical studies, hiking and camping in and near estuaries.

Estuaries provide a place for families and friends to enjoy their hobbies and spend time together in unique and beautiful areas. And, these activities, often called eco-tourism, support local economies near estuaries. Fishermen buy fresh bait, tackle and food. Boaters pay marina fees and perhaps hotel fees. Tourists eat in local restaurants and buy local goods. Coastal and marine waters contribute $30 billion to the U.S. economy through recreational fishing, and provide a tourism destination for 89 million Americans each year.

Some students visit estuaries, on trips or virtually through online field trips, to experience their beauty and learn about the complex processes that take place in estuaries.

Pennsylvania Initiative
Marina and Boater Pollution Prevention Initiatives – Sea Grant PA

According to the Pennsylvania Fish and Boat Commission, Pennsylvania is home to 148 marinas and 355,000 registered boats. Recreational boating in the Pennsylvania waters of Lake Erie and the Delaware River is a popular activity, drawing many local and out-of-town participants. However, marina operators and recreational boaters may not be aware of their potential impact on the Commonwealth's water quality. Concern has been expressed regarding the impact marina operations and recreational boaters have on water quality and the potential lack of information available to marina operators. Pennsylvania Sea Grant conducted a survey of the marinas along the Pennsylvania shore of Lake Erie, and the results indicated that marina operators had a lack of information on spill response, recycling, and other environmentally sound business practices.

The Clean Marina Initiative is a voluntary, incentive-based program promoted by NOAA and others that encourages marina operators and recreational boaters to protect coastal ecosystems by engaging in environmentally sound practices. While clean marina programs vary from state to state, they share a common goal of providing information, guidance, and technical assistance to marina operators, local governments, and recreational boaters on pollution-reducing best management practices. Marinas that participate in a clean marina program are recognized for their environmental stewardship, thus providing mutual benefit to the operator and the environment. In the Delaware watershed, staff works with the *Smart Boating Clean Waters* project to educate boaters and marina operators on pollution prevention activities. To address boater education in Erie, Pennsylvania Sea Grant staff work with the Erie Safe Boating Task Force and Erie Power Squadron, the local representative of the U.S. Power Squadron that is dedicated to the advancement of safe boating education and provides educational materials and classes in a wide array of safe boating disciplines.

For boater safety issues, staff works closely with the Erie Safe Boating Task Force in the development of information and materials to enhance safe and clean boating among recreational boaters in Presque Isle Bay and Lake Erie. In conjunction with PASG, the Erie Safe Boating Task Force, which has been active in the area since 1994, has developed a variety of educational initiatives to promote safe boating practices.

Cultural Importance

Estuaries offer cultural importance to Americans. They are often city and trade centers, they are an important source of food, they buffer communities from storm surges, and they have a long history of cultural use by Native Americans.

To many communities, estuaries are rivers of life. Estuaries are close to cultural and population hubs like New Orleans, San Francisco and New York City. Over 50% of the U.S. population lives near the coast.

Seafood provides an important food source for the country. U.S. consumers spent an estimated $69.5 billion on fishery food products (via restaurants, carry-outs, retail sales for home consumption, etc.) in 2006. Besides fish and shellfish, many different types of kelp and algae can be eaten or used in processed foods.

Salt marsh soils and grasses buffer floods, absorb excess water and slow down storm surges. They protect and buffer coastal shores, towns and communities from ocean waves and storms.

Many Native Americans historically, and still today, rely on estuaries for their way of life. Historically, tribes traded shells (wampum) as currency. They used shells as gifts, decoration, tools and spearheads. Local clay was used for making pottery (pots, cups, plates). Coastal reeds were utilized for basket weaving, cooking, mats, and building homes. Hunting and fishing in and near estuaries occurred with hewn out log canoes, hook and lines, casting nets, hand made spears, bows and arrows depending on the seasonal variety of animals and fish. Present day tribes still rely on fishing and shellfish for food and income.

Environmental Benefits

Estuaries provide critical habitat for species that are valued commercially, recreationally, and culturally. Birds, fish, amphibians, insects, and other wildlife depend on estuaries to live, feed, nest, and reproduce. Some organisms, like oysters, make estuaries their permanent home; others, like horseshoe crabs, use them to complete only part of their life cycle (Sumich, 1996). Estuaries provide stopovers for migratory bird species such as mallard and canvasback ducks. Many fish, including American shad, Atlantic menhaden and striped bass, spend most of their lives in the ocean, but return to the brackish waters of estuaries to spawn. (NOAA)

Economic Benefits

Estuaries are often the economic centers of coastal communities. Estuaries provide habitat for more than 75 percent of the U.S. commercial fish catch, and an even greater percentage of the recreational fish catch (National Safety Council's Environmental Center, 1998). The total fish catch in estuaries contributes $4.3 billion a year to the U.S. economy (ANEP, 1998).

Many estuaries support healthy recreational fisheries. This, in turn, provides financial security for communities that rely on tourists to support their economies. (Photo: Rookery Bay NERRS site)

Estuaries are also important recreational areas. Millions of people visit estuaries each year to boat, swim, watch birds and other wildlife, and fish. Coastal recreation and tourism generate from $8-$12 billion per year in the United States alone (National Safety Council's Environmental Center, 1998).

Many estuaries are important centers of transportation and international commerce. In 1997, commercial shipping employed over 50,000 people in the United States (National Safety Council's Environmental Center, 1998). Many of the products you use every day pass through one or more estuaries on a commercial shipping vessel before ever reaching your home.

The continuing prosperity many coastal communities reap from transportation, fishing and tourism is clearly linked to the health of their estuaries. The economy and the environment are completely intertwined. (NOAA)

Healthy estuaries provide tranquil oases where canoeists, kayakers, sailors, fishers, and many others can appreciate nature. Coastal recreation and tourism generate from $8-$12 billion per year in the United States alone. (Photo: Rookery Bay NERRS site)

Birdwatching is a hobby enjoyed by millions of Americans. Healthy estuarine ecosystems provide excellent opportunities for birders to see diverse avian species in their native surroundings. (Photo: Rookery Bay NERRS site)

Why Are Estuaries Important? Ecosystem Services

In addition to providing economic, cultural and ecological benefits to communities, estuaries deliver invaluable ecosystem services. Ecosystem services are fundamental life-support processes upon which all organisms depend (Daily et al., 1997). Two ecosystem services that estuaries provide are water filtration and habitat protection.

Habitats associated with estuaries, such as salt marshes and mangrove forests, act like enormous filters. As water flows through a salt marsh, marsh grasses and peat (a spongy matrix of live roots, decomposing organic material, and soil) filter pollutants such as herbicides, pesticides, and heavy metals out of the water, as well as excess sediments and nutrients (USEPA, 1993).

One reason that estuaries are such productive ecosystems is that the water filtering through them brings in nutrients from the surrounding watershed. A watershed, or drainage basin, is the entire land area that drains into a particular body of water, like a lake, river or estuary. In addition to nutrients, this same water often brings with it all of the pollutants that were applied to the lands in the watershed. For this reason, estuaries are some of the most fertile ecosystems on Earth, yet they may also be some of the most polluted.

Estuaries and their surrounding wetlands are also buffer zones. They stabilize shorelines and protect coastal areas, inland habitats and human communities from floods and storm surges from hurricanes. When flooding does occur, estuaries often act like huge sponges, soaking up the excess water. Estuarine habitats also protect streams, river channels and coastal shores from excessive erosion caused by wind, water and ice.

Unlike economic services, ecosystem services are difficult to put a value on, but we cannot do without them, and thus, they are essentially priceless. [(NOAA)]

What Role do Estuaries Play in Earth's Cycles?

Estuaries are connected to many different cycles on Earth including the nutrient cycle, the water cycle and the cycle of life. In the nutrient cycle, estuaries serve as a place where many elements are recycled and made available to living organisms. These elements must be kept in balance to maintain the health of the estuary. In the water cycle, estuaries serve as places where evaporation of water occurs, and also serve to recharge ground water. In the cycle of life, estuaries provide shelter, food and nursery grounds for animals. Decomposing animals in estuaries can provide nutrients for other organisms.

Estuaries are places where water, nutrients, organic material, and minerals recycle. For example, in estuaries, minerals and nutrients build up, while floods and rains flush them out to be recycled in the nutrient cycle. Also, fresh water and saltwater mix and recycle as part of the water cycle. Animals migrate in and out of estuaries, reproduce, die, decompose and replenish organic matter. Just as the sun rises and sets, Earth's cycles begin and end, to begin again. Estuaries play an important role in these cycles. (Estuaries 101)

Estuaries' Role in the Nutrient Cycle

In the nutrient cycle, estuaries serve as a place where many elements are recycled and made available to living organisms. These elements must be kept in balance to maintain the health of the estuary.

In ecology and Earth science, a nutrient cycle, or a biogeochemical cycle, is the recycling of nutrients, or chemical elements and compounds that are necessary for life. Nutrients move through both living and non-living compartments of an ecosystem. These nutrients and elements are used in ecosystems by living organisms. Some important nutrient cycles include the carbon cycle, the nitrogen cycle, the oxygen cycle and the phosphorus cycle.

Nutrients must be balanced in all parts of the cycles. If nutrients become unbalanced in one compartment, the health of the ecosystem may decline.

The cycling of two nutrients, nitrogen and phosphorus, is especially important in estuaries. Nitrogen and phosphorus come from several sources including decomposing animals and plants, animal waste, fertilizer, runoff including products such as laundry detergent, and more. In the soil and the water of the estuary, bacteria and other living organisms like microscopic plants must have these nutrients to grow. Often, as the amount of nutrients increases, the numbers of the organisms that require the nutrients increases.

For example, when a large amount of animal waste that is high in nitrogen is deposited in a nearby stream, the estuary downstream will receive a large amount of this nutrient, causing an unbalanced state. With extra nutrients like nitrogen, algae may grow in high numbers, or "bloom". When the algae use up the extra nutrients, they die and decompose. The process of decomposition uses oxygen and can deplete surrounding estuarine waters of its oxygen, creating anaerobic conditions. Such conditions can cause fish and shellfish, which need oxygen to survive, to die. (Estuaries 101)

Estuaries' Role in the Water Cycle

In the water cycle, estuaries serve as places where evaporation of water occurs, and also serve to recharge ground water.

Rain falls onto the surface of the earth and runs into lakes, streams and rivers. This runoff flows down slopes and steep hills into large rivers. Rivers wind past cities and towns to empty into estuaries and coastal oceans. Water held in bays and lagoons of estuaries recharges the ground water. The hot sun beats down on water in estuaries; water molecules warm up, become more active and evaporate. In estuaries, liquid water changes into water vapor, a gas form of water. Some water also evaporates from estuarine vegetation.

As water vapor rises from estuaries, cold air above Earth's surface causes water vapor to cool. By condensation, water vapor mixes with tiny particles of dust, salt and smoke to form cloud droplets. Cloud droplets collect to become clouds. Winds push clouds around Earth. Steep mountains slow down passing clouds. Water vapor in clouds cools; water molecules congregate, become heavy, and form precipitation. Precipitation falls as rain, sleet, hail or snow. The water cycle starts once more. (Estuaries 101)

Estuaries' Role in the Cycle of Life

In the cycle of life, estuaries provide shelter, food and nursery grounds for animals. Decomposing animals in estuaries can provide nutrients for other organisms.

Life abounds in estuaries. Some animals live in estuaries year round. Others pass through on their migration route, while others visit estuaries temporarily to reproduce. For example, migrating birds of all different species stop off to rest, refuel, and continue to their specific destinations. Deer and elk migrate through to their winter, or summer habitats. Young salmon whisk in and out of sea grass before they migrate into the ocean. And some species of salmon even migrate across estuaries to go from ocean to fresh water, or vice versa.

As plants and animals die and decompose in estuaries, the decaying matter adds nutrients, or organic matter, to the estuarine system for other animals to use as energy.

Life cycles and recycles in estuaries. Animals, plants, insects and marine life actively participate in the food web. From microscopic phytoplankton, flashing manta rays to a wading deer, life lives and dies in estuaries. Their bodies decompose to recycle nutrients and organic matter.

In all estuaries, animals and plants rely on each other through the food web. Plants in estuaries are producers. They can also be called autotrophs, a type of producer that makes its energy using sun light through a process called photosynthesis. Producers are important to the productivity of estuaries, because they are the base of the food web. Some bacteria are also important producers. These bacteria, also called decomposers, break down dead animals and plants. They are very important to estuaries because they recycle organic matter and nutrients back into the soil and water. Decomposers work at all levels of the food web. Other living organisms are consumers. Consumers eat producers and other consumers.

Consumers (fish, shorebirds, frogs) may eat one or more kind of plant, insect, fish or small reptile. Larger predators (snakes, hawks, fish) consume small consumers. Populations depend on their prey for energy. If a disturbance occurs in one population level, it may have consequences for the predators of that organism, and for other trophic levels above and below it. (Estuaries 101)

The Constantly Changing Estuary

Estuaries are dynamic, constantly changing places. Changes in estuaries are caused by tides, water circulation, waves, wind, weather, and climate. Survival for estuarine organisms can be difficult, but many estuarine animals and plants have adapted to tolerate the varying conditions of estuaries. Changing conditions are an integral and necessary part of healthy, functioning estuaries. (Estuaries 101)

Tides Create Cyclical Changes in Estuaries

Tides are necessary for healthy estuaries as they flush the systems and provide nutrients to keep the food webs functional. However, tides create constantly changing conditions of exposure to air and inundation to water.

Earth's gravity holds our oceans and seas to its surface. At the same time, the sun and moon's gravity forces pull on the oceans. Water on one side of Earth is pulled toward the moon and bulges out (creating a tidal bulge). Another tidal bulge on the opposite side of Earth occurs because the water on that side, being farther away from the moon, is not pulled toward the moon as strongly as is the earth. As Earth rotates, different places on the planet's surface experience the tidal bulge, and therefore experience changes in water levels. This daily rise and fall of the oceans are called tides.

Tides flood as the waters rise on the coast, pushing seawater into an estuary. Tides ebb and the waters flow out to sea. Tides ebb and flood on cycles over a 24-hour period. Each day, estuaries can have one or two high tides, plus one or two low tides. Animals and plants must adapt to this daily water level change, or they won't survive. Tides are necessary for healthy estuaries as they flush the systems and provide nutrients to keep the food webs functional.

As the tide ebbs and flows, the intertidal zone is once exposed to the elements and then inundated by tidal waters. In addition to the alternating wet and dry conditions, organisms must adapt to the waves that are in constant action in this zone.

Do you think there are differences in tidal range, the change between low and high tide, around the world? In the Katchemak Bay in Alaska, spring tides can have a 20-22 foot tidal range between extreme low and high tides. Grand Bay in Mississippi experiences a much lower tidal range (1- 2 feet) in the spring. (Estuaries 101)

Tidal Zones

Estuaries can also be divided into tidal zones (supratidal, intertidal, and subtidal) subject to changing water levels, temperature, oxygen content, and levels of light.

With the incoming and ebbing tide, life exists in zonal habitats. Zonation describes the different zones or areas of the estuarine environment. Different organisms live in different zones depending on what conditions they are adapted to.

Supratidal Zone

The supratidal zone is the area above the high tide water line that extends upland. This area is seldom covered by water. Some part of this zone can receive moisture from wave splash. Land-based or terrestrial animals and plants survive here if they can tolerate some seawater or brackish water. Marine animals and plants survive here if they can tolerate exposure to air. Some examples of organisms in the zone include: various trees, and shrubs, mammals such as deer and fox, birds, reptiles and much more.

Intertidal Zone

The intertidal zone is the area that is exposed to the air at low tide and submerged at high tide. This area can include many different types of habitats, including steep rocky cliffs, sandy beaches or vast mudflats. Organisms in the intertidal zone are adapted to harsh extremes. Water can be high due to tides, rain and run off, and this water can be very salty at one time and very fresh another. These areas can also become very dry when tides are low for extended periods of time. Temperatures can range from very hot with full sun to freezing in colder climates. Some examples of organisms that live in the intertidal zone include: shore birds, marsh grasses, shrimp and fish (when water is present), snails, mussels and oysters, burrowing worms and much more.

Subtidal Zone

The subtidal zone is the area below the low tide water line. This area is always covered by water. This area can include many different types of habitats, including soft and hard bottom, submerged aquatic vegetation beds and coral reefs. The organisms here cannot tolerate very long exposure to the air or sun. Some examples of organisms that live in the subtidal zone include: eel grass, algae, fish, starfish, shrimp, crabs, dolphins and much more.

Water Depth and Estuary Location

The depth and location of an estuary affects and changes conditions such as temperature and number of organisms present.

Shallow estuarine waters allow great temperature changes. The sun heats up the estuary during the day, and cool waters from rivers and the sea enter the estuary by night. Tides also affect estuarine temperatures. At high tide, the deeper, lower reaches of the estuary remain cool, and only the top layers are heated by the sun. As the tide goes out, heating occurs more rapidly. Some estuarine organisms can withstand the variable estuarine temperatures, while others cannot and attempt to escape.

In estuaries in temperate or polar regions there are high temperature differences which can result in a low number of plants and animals. In estuaries in tropical areas, where water temperature is more stable, the number of plants and animals is less affected. (Estuaries 101)

Weather, Seasons and Climate Create Change in Estuaries

Weather patterns, seasonal cycles and climate change affect and change conditions in estuaries. The Earth's climate is warming at a faster rate than normal. This warming is causing sea level to rise, which may ultimately result in flooded and lost estuaries.

Weather patterns, seasonal cycles and climate change affect and change conditions in estuaries such as structure, temperature and water quantity and quality.

When wind blows across water, waves are formed. Waves carry energy and help stir up and mix nutrients, silt and decaying matter in an estuary. Large waves, often caused by storms, travel in from the ocean and carry lots of energy. This energy is released when the waves crash and pound into barrier reefs, sandbars and the open shore. The pounding energy can wash away sediments. Waves can also pound logs and debris that disturb sediment and sessile animals such as mussels and barnacle shores.

In addition to waves, currents caused by wind can cause changes to estuaries. Currents move sand and sediment in and out of estuaries and can erode away shorelines. Currents move floating organisms, such as phytoplankton and jellyfish, and plants through an estuary. Currents also deposit sediment, replenishing barrier islands and sandbars. (Estuaries 101)

Estuary Classification

Estuaries are classified based on two characteristics: their geology and how saltwater and fresh water mix or circulate in them.

Classifying Estuaries - by Geology

The features of an estuary are determined by a region's geology, and influenced by physical, chemical, and climatic conditions. For example, movements in the Earth's crust elevate or lower the coastline, changing the amount of seawater that enters an estuary from the ocean. The coastal elevation also determines the rate of fresh water that flows into an estuary from rivers and streams. The amounts of seawater and fresh water flowing into an estuary are never constant. The quantity of seawater in an estuary changes with the changing tides, and the quantity of fresh water flowing into an estuary increases and decreases with rainfall and snowmelt. (NOAA)

Estuaries are typically classified by their existing geology or their geologic origins (in other words, how they were formed). The five major types of estuaries classified by their geology are coastal plain, bar-built, deltas, tectonic and fjords. In geologic time, which is often measured on scales of hundreds of thousands to millions of years, estuaries are often fleeting features of the landscape. In fact, most estuaries are less than 10,000 years old (Levinton, 1995).

Coastal plain estuaries, or drowned river valleys, are formed when rising sea levels flood existing river valleys. Bar-built estuaries are characterized by barrier beaches or islands that form parallel to the coastline and separate the estuary from the ocean. Barrier beaches and islands are formed by the accumulation of sand or sediments deposited by ocean waves.

A delta, characterized by large, flat, fan-shaped deposits of sediment at the mouth of a river, occurs when sediments accumulate more rapidly than ocean currents can carry them away. When the Earth's tectonic plates run into or fold up underneath each other, they create depressions that form tectonic estuaries. Fjords are steep-walled river valleys created by advancing glaciers, which later became flooded with seawater as the glaciers retreated. (NOAA)

Coastal Plain Estuaries

Chesapeake Bay on the East Coast of the United States and Coos Estuary on the West Coast are both coastal plain estuaries. These, and most other coastal plain estuaries in North America, were formed at the end of the last ice age between 10,000-18,000 years ago. As glaciers receded and melted, sea levels rose and inundated low-lying river valleys. Coastal plain estuaries are also called drowned river valleys.

Other examples of coastal plain estuaries include the Hudson River in New York, Narragansett Bay in Rhode Island, the Thames River in England, the Ems River in Germany, the Seine River in France, the Si-Kiang River in Hong Kong, and the Murray River in Australia. (NOAA)

Bar-built Estuaries

Bar-built or restricted-mouth estuaries occur when sandbars or barrier islands are built up by ocean waves and currents along coastal areas fed by one or more rivers or streams. The streams or rivers flowing into bar-built estuaries typically have a very low water volume during most of the year. Under these conditions, the bars may grow into barrier beaches or islands and the estuary can become permanently blocked. The areas between the coast and the barrier beaches or islands are protected areas of calm water called lagoons.

Barrier beaches or islands break the impact of destructive ocean waves before they can reach the estuary and mainland, consequently protecting them. The barrier beaches take the brunt of the waves' force and are sometimes completely washed away, leaving the estuary and coast exposed and vulnerable. During heavy rains, large volumes of water flowing down the river or stream can also completely wash away small bars and reopen the mouth of the estuary (Ross, 1995; Sumich, 1996).

Bar-built estuaries are common along the Gulf Coast of Texas and Florida, in the Netherlands, and in parts of North Carolina. Good examples are Pamlico Sound in North Carolina, Matagorda Bay in Texas, and the Nauset Barrier Beach System on Cape Cod, Massachusetts. (NOAA)

Deltas

Deltas form at the mouths of large rivers, when sediments and silt accumulate rather than being washed away by currents or ocean waves. Over time, a complex set of channels, sand barriers and marshes form at the mouth of the river. As sediments continue to accumulate, the course of the river may even be changed. The name delta comes from the resemblance of the triangular fan-shaped mouth of the famous Nile River Delta to the Greek letter delta (Δ).

Bar-built estuaries and deltas both have large deposits of silt, mud and sand near their mouths, but the processes forming each of these estuaries are quite different. In deltas, sediments are carried downstream and deposited at the mouth of the river. Bar-built estuaries are formed by ocean waves and currents pushing sediments shoreward, building up sandbars and forming barrier islands (Ross, 1995; Sumich, 1996).

The image below is the Mississippi Delta as viewed from space. The city of New Orleans is in the center left-hand side of the image. The massive deposits of sand and silt that make up the delta appear light tan in color, surrounding the peninsula. (Photo: Weeks Bay NEERS site) (NOAA)

Tectonic Estuaries

The first stage in the formation of a tectonic estuary is when the rapid movement of the Earth's crust causes a large piece of land to sink, or subside, producing a depression or basin. These drastic changes typically occur along fault lines during earthquakes. If the depression sinks below sea level, ocean water may rush in and fill it. The same geological forces that create these depressions often form a series of natural channels that drain fresh water from nearby rivers and streams into these newly formed basins. The mixture of seawater and fresh water creates a tectonic estuary. Estuaries formed in this manner are typically very deep and surrounded by mountainous areas. San Francisco Bay, on the West Coast of the United States, is an excellent example of a tectonic estuary. (NOAA)

Fjords

Fjords (pronounced fee-YORDS) are typically long, narrow valleys with steep sides that are created by advancing glaciers. The glaciers leave deep channels carved into the earth with a shallow barrier, or narrow sill, near the ocean. When the glaciers retreat, seawater floods the deeply incised valleys, creating estuaries. Fjords tend to have a moderately high input of freshwater. In comparison, very little seawater flows into the fjord because of the sill. In addition, the sill prevents deep waters in the fjord from mixing with deep waters of the sea. This poor water exchange results in stagnant, anoxic (low oxygen) water that builds up on the bottom of the fjord.

Not surprisingly, fjords are found in areas that were once covered with glaciers. Glacier Bay in Alaska and the Georgia Basin region of Puget Sound in Washington State are good examples of fjords. Fjords are also found throughout Canada, Chile, New Zealand, Greenland, Norway, Siberia, and Scotland.

This satellite image of Glacier Bay Alaska shows many characteristic long narrow fjords that have been carved out of the surrounding terrain by advancing glaciers. (NOAA)

Classifying Estuaries - By Water Circulation

In addition to classifying estuaries based on their geology, scientists also classify estuaries based on their water circulation. The five major types of estuaries classified according to their water circulation include salt-wedge, fjord, slightly stratified, vertically mixed, and freshwater (Levinson, 1995; USEPA, 1993).

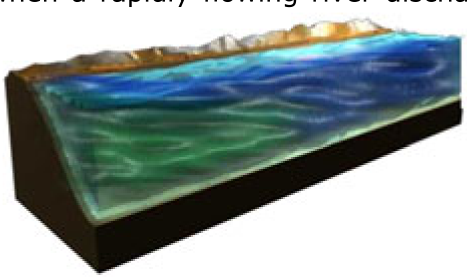
Water movement in estuaries transport organisms, circulate nutrients and oxygen, and transport sediments and wastes. Once or twice a day, high tides create saltwater currents that move seawater up into the estuary. Low tides, also once or twice a day, reverse these currents. In some estuaries, the mixing of fresh water from rivers and saltwater from the sea is extensive; in others it is not. In the Hudson River in New York, for example, tidal currents carry saltwater over 200 km upstream.

The daily mixing of fresh water and saltwater in estuaries leads to variable and dynamic chemical conditions, especially salinity. When fresh water and saltwater meet in an estuary, they do not always mix very readily. Because fresh water flowing into the estuary is less salty and less dense than water from the ocean, it often floats on top of the heavier seawater. The amount of mixing between fresh water and seawater depends on the direction and speed of the wind, the tidal range (the difference between the average low tide and the average high tide), the estuary's shape, and the volume and flow rate of river water entering the estuary. These factors are different in each estuary, and often change seasonally within the same estuary. For example, a heavy spring rain, or a sustained shift in local winds, can drastically affect the salinity in different parts of an estuary (Sumich, 1996).

The degree to which fresh water and saltwater mix in an estuary is measured using isohalines. Isohalines are areas in the water that have equal salt concentrations, or salinities. The shape of the isohalines indicates the amount of mixing that is occurring, and may provide clues about the estuary's geology (Sumich, 1996). To determine isohalines, scientists measure the water's salinity at various depths in different parts of the estuary. They record these salinity measurements as individual data points. Contour lines are drawn to connect data points that have the same salinity measurements. These contour lines show the boundaries of areas of equal salinity, or isohalines, and are then plotted onto a map of the estuary. The shape of the isohalines tells scientists about the type of water circulation in that estuary (Sumich, 1996). (NOAA)

Salt-wedge Estuaries

Salt-wedge estuaries are the most stratified, or least mixed, of all estuaries (Molles, 2002; Ross, 1995). They are also called highly stratified estuaries. Salt-wedge estuaries occur when a rapidly flowing river discharges into the ocean where tidal currents are weak. The force of the river pushing fresh water out to sea rather than tidal currents transporting seawater upstream determines the water circulation in these estuaries. As fresh water is less dense than saltwater, it floats above the seawater. A sharp boundary is created between the water masses, with fresh water floating on top and a wedge of saltwater on the bottom. Some mixing does occur at the boundary between the two water masses, but it is generally slight. The location of the wedge varies with the weather and tidal conditions. Examples of salt-wedge estuaries are the Columbia River in Washington and Oregon, the Hudson River in New York, and the Mississippi River in Louisiana.

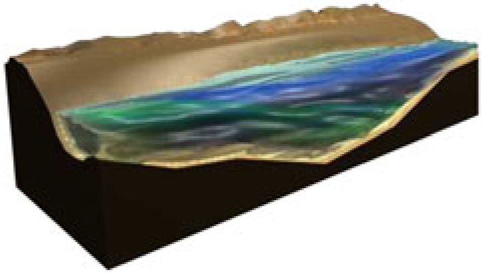


Salt-wedge estuaries are the most stratified, or least mixed, of all estuaries.

In the diagram, the blue-colored fresh water flows from the river on the right-hand side of the image over a green-colored wedge of salty seawater as it moves out toward the ocean on the left-hand side of the image. (NOAA)

Fjord-type Estuaries

Fjords (pronounced fee-YORDS) are typically long, narrow valleys with steep sides that were created by advancing glaciers. As the glaciers receded they left deep channels carved into the earth with a shallow barrier, or narrow sill, near the ocean. The sill restricts water circulation with the open ocean and dense seawater seldom flows up over the sill into the estuary. Typically, only the less dense fresh water near the surface flows over the sill and out toward the ocean. These factors cause fjords to experience very little tidal mixing; thus, the water remains highly stratified. Fjords are found along glaciated coastlines such as those of British Columbia, Alaska, Chile, New Zealand, and Norway.



Fjords are typically long, narrow valleys with steep sides that were created by advancing glaciers.

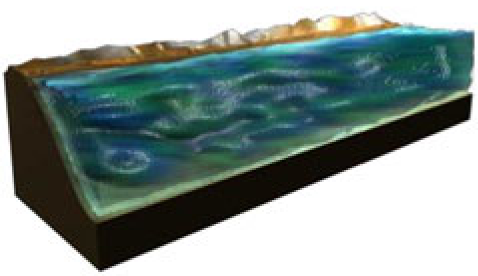
In the diagram, the blue-colored fresh water is seen flowing over the narrow sill of the fjord on the far right-hand side of the image into the ocean. Almost none of the green-colored seawater is able to make it over the sill into the estuary. (NOAA)

Slightly Stratified Estuaries

In slightly stratified or partially mixed estuaries, saltwater and freshwater mix at all depths; however, the lower layers of water typically remain saltier than the upper layers. Salinity is greatest at the mouth of the estuary and decreases as one moves upstream. Very deep estuaries, such as Puget Sound in Washington State and San Francisco Bay in California, are examples of slightly stratified estuaries (Ross, 1995). Even though Puget Sound is classified as a fjord in terms of its geology, it does not exhibit the characteristics of a fjord when classified by water circulation. (NOAA)

Vertically Mixed Estuary

A vertically mixed or well-mixed estuary occurs when river flow is low and tidally generated currents are moderate to strong (Ross, 1995). The salinity of water in a vertically mixed estuary is the same from the water's surface to the bottom of the estuary. Strong tidal currents eliminate the vertical layering of fresh water floating above denser seawater, and salinity is typically determined by the daily tidal stage. The estuary's salinity is highest nearest the ocean and decreases as one moves up the river. This type of water circulation is often found in large, shallow estuaries, such as Delaware Bay. (NOAA)



The salinity of water in a **vertically mixed** estuary is the same from the water's surface to the bottom of the estuary.

Freshwater Estuaries

We normally think of estuaries as places where rivers meet the sea, but this is not always the case. Freshwater or Great Lakes-type estuaries do not fit the definition of a brackish water estuary where freshwater and seawater mix.

Freshwater estuaries are semi-enclosed areas of the Great Lakes in which the waters become mixed with waters from rivers or streams. Although these freshwater estuaries do not contain saltwater, they are unique combinations of river and lake water, which are chemically distinct. Unlike brackish estuaries that are tidally driven, freshwater estuaries are storm-driven. In freshwater estuaries the composition of the water is often regulated by storm surges and subsequent seiches (vertical oscillations, or sloshing, of lake water). While the Great Lakes do exhibit tides, they are extremely small. Most changes in the water level are due to seiches, which act like tides, exchanging water between the river and the lake.

Old Woman Creek is a freshwater estuary located on the south-central shore of Lake Erie in Ohio. Tidal changes in water level only average about 3 cm. As a storm-driven estuary system, during periods of low water flow, a barrier sand beach will often close the mouth of the estuary, isolating it from Lake Erie. Water movement through the sand barrier beach is generally very limited. (Photo: Old Woman Creek NERRS site) (NOAA)

Estuarine Habitats

A rich array of habitats surrounds estuaries. The type of habitat is usually determined by the local geology and climate. Habitats associated with estuaries include salt marshes, mangrove forests, mud flats, tidal streams, rocky intertidal shores, reefs, and barrier beaches.

Examples of nearly every type of estuarine habitat exist along the coastline of the United States. In New England, salt-tolerant grasses fill salt marshes along the shores of tidal rivers. As one travels further south, the Atlantic Coast becomes much sandier, and barrier beaches enclose huge bays or sounds. In this region, estuarine habitats cover large areas along tidal rivers, and salt marshes reach far inland. Along the southern coast of Florida and lining the Gulf of Mexico are extensive mazes of mangrove forests, also called mangals.

From northwestern Florida to the Texas coast are long, narrow, sandy barrier islands and shallow estuaries lined with marshes. Along the Texas coast, barrier islands protect estuaries that have formed narrow lagoons with small openings to the Gulf of Mexico. In these areas, estuaries with very little freshwater input often become hypersaline or super salty.

Along the Pacific Coast of the United States, from northern California to Alaska, coastal rivers flow quickly out of the mountains and into very small estuaries. San Francisco Bay is one of the largest estuaries on the U.S. West Coast, and one of only a few that is similar in size to those found on the East Coast. (NOAA)

Mangrove forests line about two-thirds of the coastlines in tropical areas of the world. They can be recognized by their dense tangle of prop roots that make the trees appear to be standing on stilts above the water. (Photo: Rookery Bay NERRS site)

Common Estuarine Habitats

Habitat is home. It is where there is shelter and safety, where there is a suitable food and water supply, where there are associated plants and animals. Estuaries can contain several types of habitats, which define the types of organisms that live there. Some common estuarine habitats are:

Water Column

The water column is the area of water from the seafloor up to the water surface. The water column contains free swimming, or pelagic, organisms and plankton (tiny drifting and floating organisms). The water column is a part of all bays, sloughs, lagoons and coastal areas; and is therefore part of an estuary. (Estuaries 101)

Oyster Reefs

Oyster reefs are communities of oysters formed by many individual oysters growing in clumps on the shells of dead oysters or other hard surfaces. Oyster reefs can be found around the entire coast of the country, except on the shores of the Great Lakes. (Estuaries 101)

Coral Reefs

Coral reefs are communities of many small individual, interconnected corals. One coral is made of a hard shell in which a small animal, called a polyp, lives. Most coral reefs are found on the shores of Hawaii, Florida and throughout the Caribbean and Pacific Ocean. (Estuaries 101)

Kelp and Other Macroalgae

Kelp and brown algae are a type of large seaweed called macroalgae. Kelp communities grow on hard surfaces at the seafloor and extend up to the water surface, like underwater trees, to create forests. Kelp forests are found on the west coast of the U.S. Other types of macroalgae may form dense beds across the bottom of the estuary. (Estuaries 101)

Rocky Shores and Bottoms

Rocky shores and bottoms are hard surfaces made of stones, boulders and bedrock. Rocky shores may have high waves and strong winds (high energy). Rocky bottoms are often flooded with exposure to air occurring only when the tide goes out. Rocky shores and bottoms are commonly found along the west and northeast coasts of the country. (Estuaries 101)

Soft Shores and Bottoms

Soft shores and bottoms are low-lying sand beaches, muddy shores and mudflats made of sediments that have mixed with detritus (think of muck or ooze). Some contain submerged and upland vegetation, some do not. Many different benthic communities (or bottom dwellers) flourish in the soft shores and bottoms including burrowing worms, snails, crabs and clams. Soft shore and bottom habitats are found along coasts across the country. (Estuaries 101)

Submerged Aquatic Vegetation

Submerged aquatic vegetation, also called SAV, are beds of leafy rooted, grass-like plants with tiny flowers, found in shallow waters where light can penetrate. They survive underwater (subtidal areas) or in areas that are both flooded and partially exposed by the tides (intertidal areas). SAV is found along coasts across the county. (Estuaries 101)

Deepwater Swamps and Riverine Forests

Deepwater swamps and riverine forests are flooded, forested wetlands growing near edges of lakes, rivers and sluggish streams. They are different from other forests because they can survive in areas with prolonged flooding. Deepwater coastal swamps and riverine forests are found across the country, but are most common along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. (2 Estuaries 101)

Salt Marshes (Coastal Marshes)

A common estuarine habitat found around the world is coastal marshes. Coastal marshes along the oceans are called salt marshes, or tidal marshes. Salt marshes prefer cool, temperate climates (winter temperatures near or below 10 C). They occur in areas that are directly affected by tidal waters.

Salt marshes are a mosaic of snaking channels called tidal creeks that fill with seawater during high tides and drain during low tides. Fish species including flounder and mullet live most of their lives in marsh creeks.

Levees are areas of higher ground that border the marsh creeks. Between the levees and tidal creeks are marsh flats, which contain pools and salt pannes. Salt pannes are shallow depressions that contain very high concentrations of salt. Pannes retain seawater for very short periods of time. When the seawater evaporates, the salts remain and accumulate over many tidal cycles. Glasswort, a plant tolerant to very high salt concentrations, is one of the only organisms able to survive in salt pannes. Pools are generally deeper than pannes, and retain water all year long (Molles, 2002). Salt-marsh snails and green crabs are some of the creatures found in pools scattered across the marsh.

Low-lying areas of the marsh are often covered with large, flat expanses of mud called mud flats (Bertness, 1999; Smith and Smith, 2000). Composed of fine silts and clays, mud flats harbor burrowing creatures including clams, mussels, oysters, fiddler crabs, sand shrimp, and bloodworms. (NOAA)

Salt marshes are salty because they are flooded by seawater every day. They are marshy because their ground is composed of peat. Peat is made of decomposing plant matter that is often several feet thick. Peat is waterlogged, root-filled, and very spongy. Because salt marshes are waterlogged and contain lots of decomposing plant material, oxygen levels in the peat are extremely low—a condition called hypoxia. Hypoxia promotes the growth of bacteria which produce the rotten-egg smell that is attributed to marshes and mud flats.

Salt marshes are covered with salt-tolerant plants, or halophytes, like salt hay, black rush, and smooth cord grass. However, these plants do not grow together in the same area. Marshes are divided into distinct zones, the high marsh and the low marsh. The difference in elevation between these two areas is usually only a few centimeters, but for the plants that inhabit each of these zones, a few centimeters makes a world of difference. The low marsh floods daily at high tide. The high marsh usually floods about twice a month during very high tides associated with new and full moons. The more often an area is flooded, the more saline it is. Plants living in salt marshes have different tolerances to salt. Those with higher tolerances are found in the low marsh, and those with lower tolerances to salt are found in the high marsh zones. Plants from one marsh zone are never found in the other.

Smooth cord grass dominates the low marsh all the way down to the estuary’s edge. It is tall, sturdy, broad-leaved, and one of the main components of peat. As one moves toward the high marsh, salt hay, a very fine-leaved grass about 1-2 feet tall, and spike grass dominate the area. The highest parts of the marsh are characterized by black rush, which grows in dense swaths.

Surrounding the high marsh are the upland habitats. Uplands are rarely, if ever, flooded with saltwater. (NOAA)

Mangrove Forests

Another common estuarine habitat found around the world is mangroves or mangals. Mangrove forests grow at tropical and subtropical latitudes near the equator where the sea surface temperatures never fall below 16°C. Mangals line about two-thirds of the coastlines in tropical areas of the world.

There are about 80 species of mangrove trees, all of which grow in hypoxic (oxygen poor) soils where slow-moving waters allow fine sediments to accumulate (Florida Department of Environmental Protection, 2000). Many mangrove forests can be recognized by their dense tangle of prop roots that make the trees appear to be standing on stilts above the water. This tangle of roots helps to slow the movement of tidal waters, causing even more sediments to settle out of the water and build up the muddy bottom. Mangrove forests stabilize the coastline, reducing erosion from storm surges, currents, waves and tides.

Just like the high and low areas of salt marshes where specific types of grasses are found, mangals have distinct zones characterized by the species of mangrove tree that grows there. Where a species of mangrove tree exists depends on its tolerance for tidal flooding, soil salinity, and the availability of nutrients. Three dominant species of mangrove trees are found in Florida mangals. The red mangrove colonizes the seaward side of the mangal, so it receives the greatest amount of tidal flooding. Further inland and at a slightly higher elevation, black mangroves grow. The zone in which black mangrove trees are found is only shallowly flooded during high tides. White mangrove and buttonwood trees, a non-mangrove species (Florida Department of Environmental Protection, 2000), face inland and dominate the highest parts of the mangal. The zone where white mangrove and buttonwood trees grow is almost never flooded by tidal waters.

A unique mix of marine and terrestrial species lives in mangal ecosystems. The still, sheltered waters among the mangrove roots provide protective breeding, feeding, and nursery areas for snapper, tarpon, oysters, crabs, shrimp and other species important to commercial and recreational fisheries. Herons, brown pelicans, and spoonbills all make their nests in the upper branches of mangrove trees. (Florida Department of Environmental Protection, 2000) (Photo: Rookery Bay NERRS site) [(NOAA)]

Adaptations to Life in the Estuary

Oysters can live in the brackish waters of estuaries by adapting their behavior to the constantly changing environment.

Mangrove trees and blue crabs are some of the estuarine species that have adapted to unique environmental conditions. In almost all estuaries the salinity of the water changes constantly over the tidal cycle. To survive in these conditions, plants and animals living in estuaries must be able to respond quickly to drastic changes in salinity.

Plants and animals that can tolerate only slight changes in salinity are called stenohaline (Sumich, 1996). These organisms usually live in either freshwater or saltwater environments. Most stenohaline organisms cannot tolerate the rapid changes in salinity that occurs during each tidal cycle in an estuary. [(NOAA)]

Plants and animals that can tolerate a wide range of salinities are called euryhaline. These are the plants and animals most often found in the brackish waters of estuaries. There are far fewer euryhaline than stenohaline organisms because it requires a lot of energy to adapt to constantly changing salinities. Organisms that can do this are rare and special. Some organisms have evolved special physical structures to cope with changing salinity. The smooth cord grass found in salt marshes, for example, has special filters on its roots to remove salts from the water it absorbs. This plant also expels excess salt through its leaves. [(NOAA)]

Adaptations of Blue Crabs

Blue crabs live in estuaries along the United States' Atlantic and Gulf coasts. They are mobile predators whose salinity requirements change at different stages in their lives.

Adult male crabs live in the low-salinity waters upstream, while adult female crabs live in the higher-salinity waters near the mouth of the estuary. During the crabs' mating season (May to October), the high-salinity preference of the female overlaps with the lower-salinity preference of the male (Zinski, 2003). After mating, female crabs migrate offshore, sometimes up to 200 km, to high-salinity waters to incubate their eggs. The females release their larvae, called zoeae, during spring high tides. The zoeae, resembling tiny shrimp, develop in the coastal waters. Zoeae require water with a salinity over 30 ppt (parts per thousand) for optimal development, which is only found in the ocean.

Winds and coastal currents keep the larvae near the ocean shore, until they return to the estuary as young crabs, called megalops.

When the megalops return to the estuary, they swim up and down in the water in response to light and tides. This is called vertical migration (Zinski, 2003). The young crabs use nighttime flood tides to move upriver into the shallow parts of the estuary. Eventually, the young crabs take up life on the bottom of the estuary, seeking out shallow-water habitats like seagrass beds and submerged aquatic vegetation (SAV), where they feed and gain protection from predators. [NOAA]

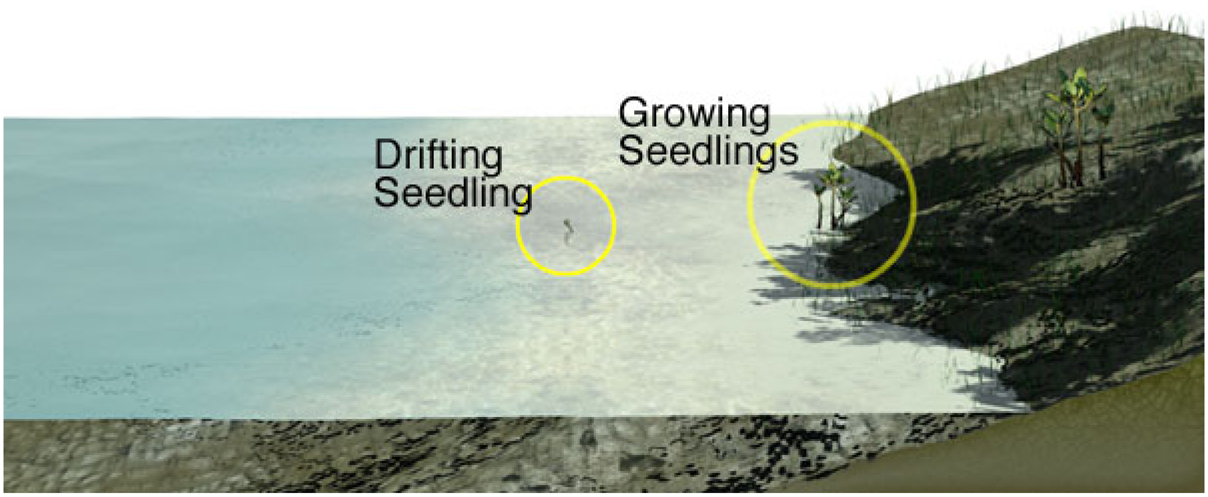
Adaptations of Mangrove Trees

Mangrove trees have become specialized to survive in the extreme conditions of estuaries. Two key adaptations they have are the ability to survive in waterlogged and anoxic (no oxygen) soil, and the ability to tolerate brackish waters.

Some mangroves remove salt from brackish estuarine waters through ultra-filtration in their roots. Other species have special glands on their leaves that actively secrete salt, a process that leaves visible salt crystals on the upper surface of the leaves.

All mangrove species have laterally spreading roots with attached vertical anchor roots. These roots are very shallow. Because the soil in shallow areas of mangal forests is typically flooded during high tides, many species of mangrove trees have aerial roots, called pneumatophores, which take up oxygen from the air for the roots. Some species also have prop roots or stilt roots extending from the trunk or other roots that help them withstand the destructive action of tides, waves, and storm surges (Smith and Smith, 2000).

Many mangrove trees also have a unique method of reproduction. Instead of forming seeds that fall to the soil below and begin growing, mangrove seeds begin growing while still attached to the parent plant. These seedlings, called propagules, even grow roots. After a period of growth, these seedlings drop to the water below and float upright until they reach water that is shallow enough for their roots to take hold in the mud (Northern Territory Government, 2000). [NOAA]



Natural Disturbances to Estuaries

This pair of images illustrates the destructive power that hurricanes can have on estuarine environments. This barrier island in Pine Beach, Alabama, was severed following hurricane Ivan's landfall in late 2004. The image on the left was taken on July 17, 2001. The image on the right was taken on September 17, 2004, soon after Hurricane Ivan reached the Alabama mainland.

Estuaries are fragile ecosystems that are very susceptible to disturbances. Natural disturbances are caused by the forces of nature, while anthropogenic disturbances are caused by people. Natural disturbances include winds, tidal currents, waves, and ice. Anthropogenic disturbances include pollution, coastal development, and the introduction of non-native species to an area.

We like to think of natural places as being stable over time, but, in fact, they are not. Natural habitats are continually disturbed by natural processes, followed by periods of recovery. When a natural disturbance is followed by an anthropogenic disturbance or vice versa, a habitat may become so damaged that it never recovers.

One type of natural disturbance is the continual pounding of ocean waves. In many estuaries, barrier beaches protect inland habitats from wave erosion. If these beaches are destroyed, salt marshes and inland habitats adjacent to the estuary may become permanently damaged. Waves can also dislodge plants and animals, or bury them with sediments, while objects carried by the water can crush them. Large storms are especially destructive to estuaries, particularly in areas like Florida and the Carolinas, where barrier beaches are common.

A common disturbance to estuaries in nontropical regions is winter ice (Bertness, 1999). Ice can freeze on an estuary's shoreline, or float freely in the water. When slabs of free-floating ice make contact with the shore, they have a scouring effect, dislodging and killing the plants and shoreline animals that lie in their path. When sheets of ice form on the shore, especially in salt marshes, they can trap plants and grass stalks inside them. During high tides, these ice sheets are lifted up, or rafted, inland to the high marsh. These rafts carry both ice and tufts of plants inshore. When the rafts settle down at low tide, they can smother inshore vegetation or scrape it from the soil. Further damage is caused as these sheets of ice and vegetation are rafted and dragged across the marsh with the ebb and flow of the daily tides.

Dead floating plant material, called wrack, is often deposited on salt marshes by high spring tides, smothering all of the plant life beneath it. (Photo: Weeks Bay NERRS site)

Another natural disturbance in salt marshes is the burial of vegetation by rafts of dead floating plant material, called wrack. Wracks can be quite large—up to hundreds of square meters, and up to 30 centimeters thick. The spring high tides often move these wracks into the high marsh, where they become stranded (Bertness, 1999). (NOAA)

Human Disturbances to Estuaries

Because we are all connected to the nation's coasts, our activities have many affects on estuaries, many of which are negative.

Do you live in the high mountains, arid deserts, or near fertile farm fields? Where ever you live, your actions affect estuaries. Everything that drains from the land feeds into many different estuaries and the oceans. Everyone lives in the watershed of an estuary. A watershed is the land area that drains into a stream, river, lake, estuary, or coastal zone.

What lakes, rivers or streams are near your home? And, where does the water in those channels travel? Wastewater (water from your yard, showers, dishwasher, etc.) drains downstream from your home or community and eventually into rivers and bays. On a map, trace water's path from your community to the ocean. Your water use affects estuaries every day. Keeping our rivers and streams clean keeps our estuaries and oceans clean.

Because they are transitional areas between the land and the sea, and between freshwater and saltwater environments, estuaries can be seriously impacted by any number of human, or anthropogenic, activities.

The greatest threat to estuaries is, by far, their large-scale conversion by draining, filling, damming or dredging. These activities result in the immediate destruction and loss of estuarine habitats. Until the last few decades, many estuary habitats in North America were drained and converted into agricultural areas; others were filled to create shipping ports and expand urban areas. In the United States, 38 percent of the wetlands associated with coastal areas have been lost to these types of activities (Good et al., 1998). In some areas, the estuarine habitat loss is as high as 60 percent.

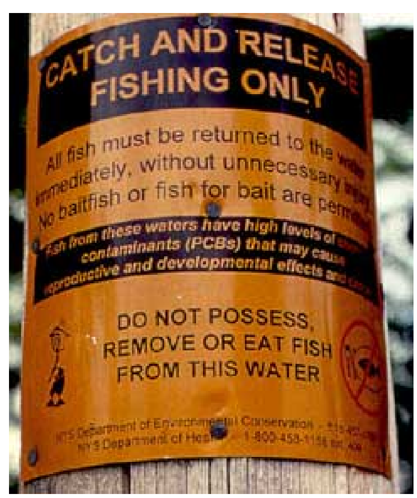
Of the remaining estuaries around the world, many are seriously degraded by pollution. People have historically viewed estuaries and waterways as places to discard the unwanted by-products of civilization. Pollution is probably the most important threat to water quality in estuaries. Poor water quality affects most estuarine organisms, including commercially important fish and shellfish.

The pollutants that have the greatest impact on the health of estuaries include toxic substances like chemicals and heavy metals, nutrient pollution (or eutrophication), and pathogens such as bacteria or viruses.

Another, less widely discussed human-caused disturbance is the introduction of non-native or invasive species into estuarine environments. (NOAA)

Toxic Substances

Toxic substances are chemicals and metals that can cause serious illness or death. They may be poisonous, carcinogenic (cancer-causing) or harmful in other ways to living things. Pesticides, automobile fluids like antifreeze, oil or grease, and metals such as mercury or lead have all been found to pollute estuaries. These substances can enter an estuary through industrial discharges, yard runoff, streets, agricultural lands, and storm drains.



Once consumed by plants and animals, some toxic substances can accumulate in these organisms' tissues. This process is called biomagnification. The insecticide DDT, and the metal mercury, are known to progressively accumulate or build up in the tissues of organisms as they make their way from the bottom of the food web (algae, shrimp, oysters, fish) to the top (osprey, eagles, bears, people).

Sometimes, toxic substances become attached to sediments (sand or mud) that flow down rivers and get deposited in estuaries. Toxic substances that enter the estuary this way often contaminate bottom-dwelling animals like oysters or clams, making them a serious health risk to people who eat them. (USEPA, 1993; USEPA, date unknown) (NOAA)

Nutrient Pollution - Eutrophication

Nitrates and phosphates are nutrients that plants need to grow. In small amounts they are beneficial to many ecosystems. In excessive amounts, however, nutrients cause a type of pollution called eutrophication. Eutrophication stimulates an explosive growth of algae (algal blooms) that depletes the water of oxygen when the algae die and are eaten by bacteria. Estuarine waters may become hypoxic (oxygen poor) or anoxic (completely depleted of oxygen) from algal blooms. While hypoxia may cause animals in estuaries to become physically stressed, anoxic conditions can kill them.

Nutrient pollution often causes explosive algal growth, which depletes the water of oxygen when the algae die. Toxic and foul-smelling compounds may also be produced through this process. (Photo: Weeks Bay NERRS site)

Eutrophication may also trigger toxic algal blooms like red tides, brown tides, and the growth of *Pfiesteria. Pfiesteria* is a single-celled organism that can release very powerful toxins into the water, causing bleeding sores on fish, and even killing them. Although consuming fish affected by this toxin is not harmful to humans, exposure to waters where *Pfisteria* blooms occur can cause serious health problems (USEPA, 1998; Howarth et al., 2000).

Eutrophication is often devastating to animals and plants in estuaries as well as the economies of communities surrounding estuaries. Toxic algal blooms disrupt tourism due to foul odors and unsightly views, and poisoned fish and shellfish adversely affect recreational and commercial fisheries (Carpenter, 1998; Howarth et al., 2000).

Nutrient pollution is the single largest pollution problem affecting coastal waters of the United States (Howarth et al., 2000). Most excess nutrients come from discharges of sewage treatment plants and septic tanks, stormwater runoff from overfertilized lawns, golf courses and agricultural fields. Over 60 percent of the coastal rivers and bays in the United States are moderately to severely affected by nutrient pollution (Howarth et al., 2000). (NOAA)

Pathogens

Pathogens are disease-causing organisms. They include bacteria, viruses and other parasites. Pathogens pose a major health threat to people who swim, fish, or boat in estuaries, as well as to filter-feeding animals, like oysters, mussels, and clams. These animals concentrate the pathogens in their tissues, making them dangerous for humans to eat.

Pathogens can enter estuaries from many different sources. Storm-water runoff and improper or inadequate sewage treatment may all allow disease-causing organisms to enter estuaries, affecting the plants and animals that live there, as well as the people who may consume them. (Photo: Stanne/NYSDEC)

Pathogens can come from many sources, including sewage treatment plants, leaky septic systems, pet, livestock, or wildlife wastes, and combined sewage overflows (CSOs). CSOs are probably the largest contributor of bacteria and viruses in most estuaries. They carry the combined sewage from residential, industrial, and commercial wastes in the form of sewage solids, metals, oils, grease and bacteria. During heavy rains, CSOs combine with storm water and overwhelm sewage treatment plants. The result is that untreated or partially treated waste flows directly into the estuary.

Contamination by pathogens can result in the temporary or permanent closure of beaches and shellfishing areas. In some cases, health officials may warn citizens that they should restrict the amount of fish and shellfish that they eat. (NOAA)

Invasive Species

Organisms in an estuary can be grouped by their origins. Organisms native to an estuary are those naturally found living and reproducing there. Invasive species and non-native organisms are those that do not naturally live in an estuary, but were introduced or migrated there over time. Once there, they may take over shelter food resources and local animals and plants may have to struggle harder to succeed in living and maintain a strong population. Invasive species can drive out native species, which may change the ecosystem itself, and may damage the economies of coastal communities. Because they are not normally found there, invasive species often do not have a common predator and it may be very difficult to remove them once they are established in an area.

Purple loosestrife *(Lythrum salicaria)* is one of many wetland plants that has invaded estuarine ecosystems in North America. If left unchecked, invasive species can cause tremendous ecological damage and economic losses in areas where they are introduced. (Photo: Washington State Department of Ecology)

Many invasive species are found in the U.S. A few examples of well known estuarine invasive species include: Eurasian watermilfoil, hydrilla, purple loosestrife, Asian carp, Chinese mitten crab, European green crab, lionfish, northern snakehead, nutria, and zebra mussel. (Estuaries 101)

In Pennsylvania, some of the aquatic invasive species of most concern include the zebra mussel, round goby, purple loosestrife, water chestnut, Eurasian watermilfoil, northern snakehead, and flathead catfish (invasive in eastern Pennsylvania).

Invasive species are plants and animals that have found their way into areas outside their normal geographic range. In many cases, humans have transported them to their new homes. Invasive species have been called a type of biological pollution (University of Rhode Island, 2001; Mack et al., 2000). Unlike pesticides or sewage, invasive species do not dissipate over time. With no natural enemies in their new habitat, invasive species often grow, reproduce and spread quickly. (NOAA)

Non-native species are often introduced to estuaries in the ballast water of ships. When ships are empty, they take in water to help keep them balanced. When cargo is loaded onto the ships, they release the ballast water. In addition to water, aquatic organisms are sucked into the ships' ballast tanks. When ships take on water in one part of the world and release it in another, aquatic plants and animals are transported along with the water and introduced into foreign estuaries. The San Francisco Bay estuary is probably the most invaded estuary in the world. Over 230 non-native species now live there; so many, in fact, that they now dominate the ecosystem. Over 160 invasive species are now found in the Chesapeake Bay, and their numbers are growing. Other pathways of invasive species introduction and spread include recreational boating, fishing, gardening, and aquaculture.

Invasives often cause ecological damage and economic losses where they are introduced. Competing with native species for food, or preying upon native species, invasive species have drastically reduced the populations of native species and have, in some cases, caused their extinction. Purple loosestrife, for example, was introduced to the United States from Europe as an ornamental plant in the early 1800s. Today it has invaded estuaries in 48 states, crowding out 44 species of native plants. Controlling purple loosestrife costs about $45 million a year (Pimentel et al., 1999). (NOAA)

Over fishing

Over fishing reduces the number of commercially valuable estuarine organisms, not only impacting the diversity of the ecosystem, but also impacting local economies. Also, some types of fishing can have a negative effect on estuary bottoms and the organisms living in them (the benthic communities), on juvenile fish and on by-catch, altering the estuarine food web. (2 Estuaries 101)

Dredging and filling

Filling and draining of wetlands, and dredging deep navigation channels through estuaries and wetlands ultimately destroy and damage habitat. They also change water and sediment flow. (Estuaries 101)

Dams

Changing river water flow can restrict sediment deposits and nutrient availability downstream, fish migration, and can increase saltwater intrusion into underground water tables. (Estuaries 101)

Global Climate Change

Scientists are confident that the Earth’s climate has entered a period of more rapid change than experienced over the past 1,000 years. Climate change can result in changes in the amount and timing of freshwater inputs to estuarine ecosystems, changes in temperature of the air and water, increases in sea level, more frequent and intense tropical storms, and changes in coastal currents. All of these changes can cause stress to estuarine organisms, can change where estuarine species are found, can alter estuarine processes and the physical and chemical patterns and make-up of estuaries. (Estuaries 101)

Coastal Land Use

You may have heard the saying, "We all live downstream." This is a rather simple statement intended to bring attention to complex, intertwined processes affecting water quality. Estuaries are the intermediary between oceans and land; consequently, these two factors influence their physical, chemical, and biological properties.

Changes to the coastal landscape have had serious implications for estuarine health. Estuaries are bombarded by several pollutant sources, and their impacts can be severe.

Pollutant Sources

Wherever there is human activity, there is usually a potential source of pollutants. (The figure below summarizes some common estuarine pollutants and their potential sources.)

Source	Common Pollutants	Possible Impacts
Cropland	Sediments, nutrients, pesticides	Reduced water clarity, smothered benthic habitat, toxicity to organisms, excessive algal growth, reduced dissolved oxygen, water temperature changes
Grazing land	Fecal bacteria, sediments, nutrients	Possible introduction of pathogens, reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen, water temperature changes
Forestry	Sediments	Reduced water clarity, smothered benthic habitat, water temperature changes
Mining	Acid discharge, sediments	Reduced water clarity, smothered benthic habitat, impacts on pH and alkalinity
Industrial/commercial Discharge	Sediments, toxins	Reduced water clarity, smothered benthic habitat, impacts on pH and alkalinity toxicity to organisms
Sewage treatment plants	Nutrients, suspended solids, fecal bacteria	Reduced water clarity, excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature and pH changes, possible introduction of pathogens
Construction	Sediments, toxins, nutrients	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen, water temperature changes, toxicity to organisms
Urban runoff	Sediments, nutrients, metals, petroleum hydrocarbons, bacteria	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature changes, toxicity to organisms, possible introduction of pathogens
Lawns/golf courses	Toxins, nutrients, sediments	Reduced water clarity, smothered benthic habitat, excessive algal growth, reduced dissolved oxygen/high biochemical oxygen demand, toxicity to organisms
Septic systems	Fecal bacteria, nutrients	Excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, water temperature changes, possible introduction of pathogens
Marinas/boat usage	Toxins, nutrients, bacteria	Excessive algal growth, reduced dissolved oxygen/higher biochemical oxygen demand, toxicity to organisms, possible introduction of pathogens

Estuarine pollution is generally classified as either point source pollution or nonpoint source pollution. Point source pollution describes pollution that comes from a discernable source, such as an industrial discharge or wastewater treatment plant. Point source pollution is usually identified as coming from a pipe, channel, or other obvious discharge point. Laws regulate point sources, with limits placed on the types and quantities of discharges to estuaries and other waterways.

Nonpoint source pollution (NPS), on the other hand, comes from a variety of diffuse sources that do not have a single discharge point. Examples include stormwater runoff from urban areas, marina operations, farming, forestry, and construction activities; faulty or leaking septic systems; and atmospheric deposition originating from industrial operations or vehicles. NPS pollution, which is often hard to identify and quantify, is generally more difficult and expensive to regulate and control than point source pollution. [EPA - VEMM]

Monitoring Estuaries

National Estuarine Research Reserve System

The National Estuarine Research Reserve System or NERRS is a partnership program between NOAA and U.S. coastal states that protects more than one million acres of estuarine land and water. These estuarine reserves provide essential habitat for wildlife; offer educational opportunities for students, teachers and the public; and serve as living laboratories for scientists.

The health of every reserve is continuously monitored by the NERRS System-wide Monitoring Program or SWMP (pronounced "swamp"). SWMP measures changes in estuarine waters to record how human activities and natural events affect coastal habitats.

The NERRS SWMP uses automated data loggers to monitor the temperature, depth, salinity, dissolved oxygen, turbidity, and pH of each estuary's water. These variables are recorded every 30 minutes at four stations in each of the 26 NERRS sites. They are key indicators of water quality and environmental conditions for the plants and animals that live in or use the estuary. The reserves also sample the water for nutrients (nitrogen and phosphorus) and chlorophyll on a monthly basis.

Weather can have a major impact on water quality in estuaries. For example, rainfall can increase sediment runoff, which, in turn, influences dissolved oxygen, turbidity, pH and temperature. As part of SWMP, every reserve has a weather station that collects data every 15 minutes on temperature, relative humidity, atmospheric pressure, rainfall, wind speed and direction. Several reserves are able to send real-time data as they are collected directly to Web sites on the Internet.

These data have already helped scientists gain a better understanding of how environmental conditions fluctuate in estuaries. The SWMP data have been used to detect conditions related to oyster diseases, measure the recovery of estuaries after hurricanes, and evaluate restoration projects in estuaries. [NOAA]

Citizen Monitoring Programs

Useful monitoring data will accurately portray the current chemical, physical, and biological status of the estuary. This type of information, collected systematically over time, can establish a record of water quality conditions in an estuary as well as document changes or improvements in the estuary from the past to the present. Most citizen monitoring programs serve to:

- Supplement federal, state, and local monitoring efforts;
- Educate the public;
- Obtain data from remote areas;
- Obtain data during storms or other unique events;
- Bring a problem area to light; and/or
- Document the illegal discharge of waste.

Citizen monitoring data, colleted accurately and systematically, can be an important supplement to data collected by professionals. Accurate data often have far-reaching uses that the organizers may not have anticipated at the outset of their program. Indeed, these data have potential to influence management actions taken to protect the water body. Further uses of the date include:

- Providing a scientific basis for specific management decisions and strategies;
- Contributing to the broad base of scientific information on estuary functions and the effects of estuary pollution;
- Determining multiyear water quality trends;
- Documenting the effect of nonpoint and point source pollutants on water quality;
- Indicating to government officials that citizens care about their local waterways;
- Documenting the impacts of pollution control measures; and
- Providing data needed to determine permit compliance.

Assessing water quality should not be conducted purely for the sake of monitoring itself. Ultimately, the protection and restoration of an estuary's wildlife, natural functions, and compatible human uses is of greatest concern. (EPA-VEMM)

Measures of Environmental Health

Water Temperature

Just knowing the temperature of the water in an estuary can give us a pretty good idea of how healthy it is. One important thing we can tell from water temperature is how much oxygen can be dissolved into the water.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. The more oxygen there is in the water, the healthier the ecosystem is. As the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, fresh water at 0°C can contain up to 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. Thus, seasonal water temperature (and dissolved oxygen) is an important indicator of habitat quality for many estuarine species.

The temperature of the water also tells us what types of plants and animals are able to live in the estuary. All plants and animals have a range of temperatures in which they thrive. If the water in the estuary is outside the normal seasonal temperature range in which most estuarine organisms can comfortably live, it is probably an indication that something is adversely affecting the health of the estuary. (NOAA)

pH

pH is a measure of how acidic a solution is. The pH scale ranges from 0 to 14. Solutions with a pH of less than 7 are acidic, and those with a pH greater than 7 are basic (or alkaline). Distilled water is neutral and has a pH of 7.

Knowledge of pH is important because most aquatic organisms are adapted to live in solutions with a pH between 5.0 and 9.0. The pH in an estuary tends to remain constant because the chemical components in seawater resist large changes to pH. Biological activity, however, may significantly alter pH in an estuary.

Through a process called photosynthesis, plants remove carbon dioxide (CO2) from the water and expel oxygen (O2). Since CO2 becomes carbonic acid when it dissolves in water, the removal of CO2 results in a higher pH, and the water becomes more alkaline, or basic. When algae naturally begin to increase in estuaries during the spring, pH levels tend to rise. An overabundance of algae (called an algal bloom) may cause pH levels in an estuary to rise significantly, and this can be lethal to aquatic animals. (NOAA)

Depth

Water levels in an estuary typically rise and fall with the daily tides, but they are also affected by the weather. Periods of drought or excessive rainfall affect the amount of fresh water entering the estuary from rivers or runoff, and can easily change the physical, chemical and biological conditions in an estuary.

Depending on the source of pollution, the levels of toxins, bacteria, or nutrients may rise as runoff increases due to heavy rainfall. The concentration of dissolved and suspended materials in the water, or turbidity, may increase with runoff due to storms, or during periods of drought when there is a low volume of water in the estuary and winds and waves stir up the muddy bottom at low tide. In general, when water levels are too high or too low in an estuary for prolonged periods of time, the health of the estuary, and the plants and animals that live in it, are vulnerable to damage.

The NERRS SWMP uses electronic depth gauges to determine estuarine water levels throughout the year. To verify the accuracy of these sophisticated devices, researchers often go out and take measurements the old-fashioned way, by hand. (Photo: Hudson River NERRS site) [NOAA]

Salinity

Under laboratory conditions, pure water contains only oxygen and hydrogen atoms, but in the real world, many substances are often dissolved in water, like salt. Salinity is the concentration of salt in water, usually measured in parts per thousand (ppt). The salinity of seawater in the open ocean is remarkably constant at about 35 ppt. Salinity in an estuary varies according to one's location in the estuary, the daily tides, and the volume of fresh water flowing into the estuary.

In estuaries, salinity levels are generally highest near the mouth of a river where the ocean water enters, and lowest upstream where freshwater flows in. Actual salinities vary throughout the tidal cycle, however. Salinity levels in estuaries typically decline in the spring when snowmelt and rain increase the freshwater flow from streams and groundwater. Salinity levels usually rise during the summer when higher temperatures increase levels of evaporation in the estuary.

Estuarine organisms have different tolerances and responses to salinity changes. Many bottom-dwelling animals, like oysters and crabs, can tolerate some change in salinity, but salinities outside an acceptable range will negatively affect their growth and reproduction, and ultimately, their survival.

Salinity also affects chemical conditions within the estuary, particularly levels of dissolved oxygen in the water. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases. The solubility of oxygen in seawater is about 20 percent less than it is in fresh water at the same temperature. [NOAA]

Dissolved Oxygen

Low levels of dissolved oxygen in the water can cause marine life to become very lethargic. Along the eastern shore of Mobile Bay, Alabama, many aquatic animals move into shallow waters to try to get more oxygen. Local communities refer to this phenomenon as "Jubilee." During a Jubilee, residents walk along the shore and fill their ice chests with crabs and flounders.

To survive, fish, crabs, oysters and other aquatic animals must have sufficient levels of dissolved oxygen (DO) in the water. The amount of dissolved oxygen in an estuary's water is the major factor that determines the type and abundance of organisms that can live there.

Oxygen enters the water through two natural processes: (1) diffusion from the atmosphere and (2) photosynthesis by aquatic plants. The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

DO levels are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases as the water's temperature and salinity increase. DO levels in an estuary also vary seasonally, with the lowest levels occurring during the late summer months when temperatures are highest.

Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down organic matter.

Oxygen depletion may occur in estuaries when many plants die and decompose, or when wastewater with large amounts of organic material enters the estuary. In some estuaries, large nutrient inputs, typically from sewage, stimulate algal blooms. When the algae die, they begin to decompose. The process of decomposition depletes the surrounding water of oxygen and, in severe cases, leads to hypoxic (very low oxygen) conditions that kill aquatic animals. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns supply the waters with plentiful oxygen. [NOAA]

Turbidity

Turbidity is essentially a measurement of how cloudy or clear the water is, or, in other words, how easily light can be transmitted through it. As sediments and other suspended solids increase in the water, the amount of light that can pass through the water decreases. Thus, the cloudier the water, the greater the turbidity. As algae, sediments, or solid wastes increase in the water, so does turbidity.

Turbidity affects organisms that are directly dependent on light, like aquatic plants, because it limits their ability to carry out photosynthesis. This, in turn, affects other organisms that depend on these plants for food and oxygen.

Scientists often consider turbidity of the water in connection with other factors to get a better understanding of its causes and consequences. For example, high levels of turbidity can identify problems with shoreline erosion, or sewage processing facilities not functioning properly. [NOAA]

Nutrients

Nutrients, especially nitrogen and phosphorus, are key indicators of water quality in estuaries. Plants require many nutrients (e.g., carbon, nitrogen, phosphorus, oxygen, silica, magnesium, potassium, calcium, iron, zinc, copper) to grow and reproduce. Of these, nitrogen and phosphorus are the most essential for aquatic plants.

Nitrogen and phosphorus naturally enter estuarine waters when freshwater runoff passes over geologic formations rich in phosphate or nitrate, or when decomposing organic matter and wildlife waste get flushed into rivers and streams. Manmade sources of nutrients entering estuaries include sewage treatment plants, leaky septic tanks, industrial wastewater, acid rain, and fertilizer runoff from agricultural, residential and urban areas. Too much nitrogen and phosphorus acts as a pollutant in the water. This leads to explosive blooms in algae that cloud the water and deplete it of the oxygen that is critical for aquatic animals. This is called eutrophication.

Excessive nutrient concentrations have been linked to hypoxic (very low oxygen) conditions in more than 50 percent of U.S. estuaries. Under the worst conditions, the waters of an estuary can become anoxic (having no oxygen). High nutrient concentrations have also been linked to algal blooms such as red and brown tides, some of which produce harmful toxins. Nutrients are also believed to cause the growth of the potentially toxic organism *Pfiesteria* (USGS, 1999). Red and brown algal tides and *Pfiesteria* have been linked to fish and shellfish kills, and may be harmful to human health. The image below illustrates what an estuary with a healthy input of nutrients looks like—lush and vibrant. (NOAA)

Chlorophyll

Chlorophyll is a green pigment in plants that turns light energy into food and allows plants to grow, and releases oxygen in a process called photosynthesis. The microscopic one-celled plants that float in healthy waters are called phytoplankton. By measuring the amount of chlorophyll in the water, scientists can determine the density of phytoplankton in an estuary, and the amount of primary productivity (the conversion of light energy into plant material) taking place as well.

Phytoplankton forms the base of the aquatic food web in an estuary. It is eaten by zooplankton (microscopic animals) and small fish, which, in turn, are eaten by larger creatures. The abundance of healthy animals in an estuary often depends on the amount of phytoplankton and primary productivity taking place. (NOAA)

The Future: Managing, Protecting and Restoring Estuaries

Estuaries are biologically and economically invaluable natural resources. Assaulted by natural and anthropogenic disturbances, estuaries, and the plants and animals that call them home, are in danger of disappearing if actions are not taken to protect them.

Through research, monitoring, education, and enforcement, the National Estuarine Research Reserve Program and its many partners work to preserve essential estuarine ecosystems for future generations.

During the last century, millions of acres of estuarine habitats have been destroyed; many more are in poor health and in danger of being lost. In 1996, 62% of estuaries had good water quality (USEPA, 1996). By 2000, only 49% of estuaries had good water quality (USEPA, 2000). How we choose to treat our estuaries today will have an enormous impact on their existence in the future.

Recognizing the value and importance of estuaries and the dangers facing them, Congress created the National Estuarine Research Reserve System (NERRS) in 1972. NERRS is dedicated to protecting a system of estuaries that represent the range of coastal estuarine habitats in the United States and its territories. The system protects more than one million acres of estuarine land and water in 17 states and Puerto Rico. NERRS sites serve as laboratories and classrooms where the effects of natural and human activities on estuaries can be monitored and studied by scientists and students. In addition, all estuaries, whether or not they are in the National Estuarine Research Reserve System, are protected under every U.S. state's coastal zone management program. Many states have designated estuaries as areas to preserve or restore for their conservation, recreational, ecological, historical, and aesthetic values.

When we have failed to protect estuaries, another course of action is to restore them. Restoring habitats involves removing pollutants and invasive species from the water and surrounding lands, reestablishing natural ecosystem processes, and reintroducing native plants and animals. The goal is to rebuild the estuary to a healthy, natural ecosystem that works like it did before it was polluted or destroyed.

In November 2000, the Estuary Restoration Act (ERA) was signed into law. It makes restoring our nation's estuaries a national priority, with a goal of restoring one million acres of estuarine habitat by 2010. NOAA is providing the necessary data, science, tools and long-term monitoring efforts to help reach the ERA's million-acre goal.

Restoring and Protecting Estuaries

From government agencies and laws – established to protect estuaries – to volunteer citizens groups, our coasts are protected, restored and conserved in many ways.

Why should damaged or forgotten estuaries be restored? Estuaries are the nurseries of the sea and a major stopover point for migratory animals. Coastal communities rely on estuaries for tourism, shipping and transportation, and fishing. There are a number of agencies, organizations and laws in place to help protect estuaries while allowing people to enjoy, use, and learn about them.

Many species, like these great egrets, nest and breed in estuaries around the world. If estuarine habitats are not protected, these magnificent birds, and many other species, may face extinction as their habitats disappear.

Government Agencies that Protect and Study Estuaries

NOAA's National Estuarine Research Reserve System

The National Estuarine Research Reserve System is a network of 27 protected areas established for long-term research, education and stewardship. This partnership program between the National Oceanic and Atmospheric Administration (NOAA) and the coastal states protects more than one million acres of estuarine land and water, which provides essential habitat for wildlife; offers educational opportunities for students, teachers and the public; and serves as living laboratories for scientists.

NOAA's Restoration Center

The NOAA Restoration Center is the focal point for marine and estuarine habitat restoration within NOAA. The Restoration Center is the only office within NOAA solely devoted to restoring the nation's coastal, marine, and migratory fish habitats. The Restoration Center works with a wide array of partners to restore mangrove, salt marsh, seagrass, oyster, coral reef, kelp forest, and river habitats.

EPA's National Estuary Program

The Environmental Protection Agency's National Estuary Program works to improve the quality of estuaries of national importance. EPA develops plans for attaining or maintaining water quality in an estuary. This includes protection of public water supplies and the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife, and allows recreational activities, in and on water, requires that control of point and non-point sources of pollution to supplement existing controls of pollution.

State and local governments

State and local governments implement regulations, policies and management strategies to ensure the long-term viability of their coasts and estuaries. State and local governments work with local communities and regional groups to address natural resource management issues and to conduct estuarine research and education.

Laws in Place to Protect and Study Estuaries

Coastal Zone Management Act

Established by Congress in 1972 and administered by NOAA, the Coastal Zone Management Act provides for management of the nation's coastal resources, including the Great Lakes, and balances economic development with environmental conservation.

Estuary Restoration Act

The Estuary Restoration Act was passed into law in November of 2000 and makes restoring our estuaries a national priority. The interagency Council implementing the Act published the goal of restoring one million acres of estuarine habitat by the year 2010.

Estuaries and Clean Waters Act

The Estuaries and Clean Waters Act of 2000 was passed into law in 1987. It encourages the restoration of estuary habitat through more efficient project financing and enhanced coordination of Federal and non-Federal restoration programs and it established the National Estuary Program.

Endangered Species Act

The Endangered Species Act of 1973 was signed in 1973 and provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend.

Some examples of volunteer organizations that are in place to protect and study estuaries include:

National Estuarine Research Reserve System Volunteer Opportunities

Volunteers participate in a wide range of activities vital to the reserves, including scientific monitoring, restoration projects, educational programs, administration, visitor services and fund raising.

Environmental Protection Agency’s Volunteer Water Quality Monitoring Program

Across the country, trained citizen volunteers are monitoring the condition of their local streams, lakes, estuaries, and wetlands.

Ocean Conservancy's International Coastal Cleanup

Thousands of volunteers participate from all over the globe, clearing tons of trash from oceans and waterways, and recording every piece of trash collected.

What Can You Do to Help?

Around the House

- Use lawn fertilizer sparingly, or not at all. Follow product directions carefully. You'll keep it from washing into our streams and waterways.
- Leave grass clippings on the lawn. Clippings decompose and are efficient, natural fertilizers.
- Cut grass to proper height. A little more height is healthy, leading to a deeper root system and less erosion.
- Use native plants. Gardening and landscaping with plants native to your area reduces the need for watering and fertilizing your garden.
- Think before you pour. Too many hazardous products flow from drains through sewage plants into coastal rivers and estuaries.
- Keep septic systems working properly. Pump every three years to assure proper working condition.
- Use lawn care products sparingly, or not at all. Always follow the directions carefully. If these products wash into streams, roadside ditches or street gutters, it can affect plants and animals far from your home.
- Create nontoxic pesticides. A bit of soap and water added to strained chili pepper powder does the job, and keeps harmful chemicals from ending up in nearby waterways.
- Explore safe alternatives to harsh household products. Baking soda or table salt, for instance, are safe substitutes for abrasive cleaners.
- Clean up after your pets. Animal waste adds to run-off, making water unhealthy.
- Walk, bike, carpool, use public transportation. Use your car less by combining errands.
- Use less electricity. Conserve water and lessen fossil fuel consumption.

Along the Waterfront

- Protect waterside trees and shrubs. These trees and shrubs are a protective gift along the water's edge and should not be cut, pruned or altered.
- Plant buffer strips. Restore riverside grasses, shrubs and trees to filter pollutants, sediments and excess nutrients from ground and surface water.
- Avoid erosion. Place mulch over disturbed soil in heavily used areas.
- Pave less. Hard surfaces hasten run-off and erosion.
- Curb run-off. When storm water is a problem, create a path or ledge to both capture run-off and filter pollutants through sand.

On the Beach

- Fish respectfully. Follow "catch and release" practices and keep more fish alive.
- Respect life on the rock. If you turn over rocks at the beach, remember to put them back so that animals that live on top, like barnacles, stay on the top and those that live on the bottom stay on the bottom.
- Have fun on the beach, but leave it clean. When you leave the beach or park, your trash should too. Be sure to bring enough bags to take all trash with you.
- Don't trample. To view life in coastal regions, use a canoe or kayak so you don't destroy sensitive habitats.

- Watch out for contamination. Support periodic testing to make sure that pesticides aren't contaminating golf course waters, adjacent creeks and groundwater.
- Eliminate poisons. If you hunt or fish, use nontoxic alternatives to lead shot, sinkers and jigs.

On your Boat

- Keep it friendly. Waves destroy shorelines and increase erosion. For environmentally friendly boating, observe posted speeds and "no-wake" signs.
- Secure loose items. Don't let items blow overboard and add to marine debris.
- Watch out for leaks. Be vigilant about harmful oil leaks from boat engines.
- Mop up. Use environmentally friendly cleaning products, and don't clean up by tossing debris out to sea. Trash, chemicals, plastic bags and fishing lines can pollute or strangle vulnerable marine life.
- Respect habitat. Treat the homes of vital marine life with care. Habitat and survival go hand-in-hand. When habitat disappears, some plants and animals do too.

In your Community

- Share your knowledge. Spread the word about America's estuaries. Share what you know about protecting them with your families, students, community leaders and others.
- Take action! Organize a stream or beach cleanup. Encourage your local newspaper to write a story, or ask an expert to speak at your community organization or local school.

estuaries

where rivers meet the sea

Ten Ways to Protect Estuaries

1 **Learn more about estuaries!** Visit www.estuaries.gov.

2 **Keep septic systems working properly.** Pump your system every three years.

3 **Pave less.** Hard surfaces hasten runoff and increase pollution and erosion.

4 **Adhere to "no-wake" zones when on your boat.** Waves destroy shorelines and increase erosion.

5 **Think before your pour.** Many hazardous products flow from household drains through sewage treatment plants and into coastal bodies of water.

6 **Fish respectfully.** Follow "catch and release" practices and keep more fish alive.

7 **Create non-toxic pesticides.** A bit of soap and water does the job and keeps harmful chemicals from ending up in nearby waterways.

8 **Use native plants.** Garden and landscape with plants native to your area to reduce the need for watering and fertilizing.

9 **Respect habitat.** Treat the homes of vital marine life with care. Habitat and survivial go hand-in-hand. When habitat disappears, so do many plants and animals.

10 **Take action!** Organize a stream or beach cleanup. Encourage your local newspaper to write a story, or ask an expert to speak at your community organization or local school.

Salt and Fresh Water Estuaries
Glossary

(A)

Abiotic factors (abiotic): non-living characteristics of a habitat or ecosystem that affect organisms' life processes.

Adaptation (adapt): a genetically-based body feature or behavior that allows an organism to be better suited to its environment.

Aerobic: with air, oxygen.

Algae: chlorophyll containing non-vascular organisms, plant or plant-like.

Anadromous: fish that live their adult lives in the ocean but move into freshwater streams to reproduce or spawn (for example: salmon).

Anerobic: without air, no oxygen.

Anoxic: without oxygen, anaerobic.

Anthropogenic: arising from human activity.

Aquatic organisms: organisms that live in or on the water.

Autotrophs: an organism that makes its own food from light energy or chemical energy without eating. Most green plants, many protists and most bacteria are autotrophs. Autotrophs are the base of the food chain and can also be called producers.

(B)

Back dune: area immediately behind fore dune; inhabited by mixture of grasses, beach heather and lichen.

Ballast water: water carried in ship's for stability. Water is pumped into a ship's hold to steady it; when the water is released in other oceans the organisms in it may become pests (or invasives).

Bar-built estuaries: areas where sandbars form parallel to the shore, partly enclosing the water behind them as the sandbars become islands.

Barrier beaches: spits of sand that form parallel to the shore.

Barrier islands: barrier beaches with a cross-section profile that often includes dunes, shrub thickets, maritime forests, and saltmarshes.

Beach / ocean interface: where waves meet beach.

Benthic: relating to the ocean bottom.

Benthos: bottom-dwelling flora and fauna; from tiniest microbenthos (bacteria) to medium-sized meiobenthos (nematode worms) to the highly visible macrobenthos (clams, polychaete worms).

Biogeochemical cycle: natural processes that recycle nutrients in various forms from the environment, to organisms and then back to the environment. Also called nutrient cycle.

Biotas: assemblages of living things.

Biotic factors (biotic): relationships among organisms that affect their survival.

BOD: biological oxygen demand. The amount of dissolved oxygen that will disappear from an enclosed water sample as aerobic bacteria decompose the organic material in the water.

Brackish: slightly salty water with a salinity between 0.5 ppt and 32 ppt.

Bycatch: unwanted fish or other animals caught in fishing nets by accident.

(C)

Carnivores: animals that eat other animals as opposed to herbivores, which eat only plants.

Chlorine: poisonous, gaseous substance.

Climate change: a regional change in temperature and weather patterns. Current science indicates a link between climate change over the last century and human activity, specifically the burning of fossil fuels.

Coastal plains estuary: estuary formed when rising sea level flooded existing river valley.

Coliform bacteria: bacteria commonly found in colon and used as an indicator of water contamination.

Commensalism: form of relationship in which one species gains from the interaction and the other is neither positively nor negatively affected.

Community: an association of interacting populations.

Commercial fishing: fishing for a commercial purpose, i.e. to sell the catch.

Competition: occurs between organisms using a finite resource, whether they are of the same or different species.

Condensation: the process in which water vapor changes into liquid water (such as dew, fog, or cloud droplets).

Conditions: characteristics of the environment that influence the survival of an organism but are not consumed by it (e.g., temperature, salinity).

Contamination: an undesirable element, impure or unclean, something that is not supposed to be there (such as oil or insecticides in water).

Conservation: careful preservation and protection of ecological processes and biodiversity of the environment.

Consumer: individual that eats other organisms to obtain energy rather than producing its food through photosynthesis or chemosynthesis.

Copepods: one of most common herbivorous zooplankton.

Crustaceans: anthropods having hard-shelled bodies and jointed ligaments such as crabs, shrimp and lobsters.

Currents: large-scale circulation of water caused by thermodynamics and winds.

(D)

Decomposer: an organism that feeds on and breaks down dead plant or animal matter, thus making organic nutrients available to the ecosystem.

Density: the ratio of the mass of any substance to the volume occupied by it.

Desiccation: loss of water.

Detritus: newly dead or decaying organic matter coated with bacteria.

Diatoms: one of most common groups of phytoplankton; single-celled organism that reproduces asexually.

Diel: the daily cycle; a 24-hour period.

Dinoflagellates: common type of phytoplankton, most abundant in fall; responsible for "red tides" as well as bioluminescence.

Disturbance: any event that opens up space for colonization, such as the falling of a tree in a forest or removal of marsh grass by storm waves.

Diverse: of different kinds, types, or species.

(E)

Ebb: the falling tide when the water moves out to the sea and the water level lowers.

Ecosystem: the biotic community and its abiotic environment.

Eco-tourism: travel undertaken to witness sites or regions of unique natural or ecologic quality. Often it is environmentally responsible travel that benefits nature and local communities.

Epibenthos: organisms that live on the bottom, rather than burrowed into, of an aquatic system.

Erode (erosion): the wearing away of the land by the action of water, ice or wind.

Estuarine: of or relating to an estuary.

Estuarine habitat: habitats associated with estuaries.

Estuary: a semi-enclosed body of water which has a free connection to the open sea and within which seawater is measurably diluted by fresh water derived from land drainage. Some unique Great Lakes coastal wetlands are referred to as freshwater estuaries. They occur where rivers and Great Lakes water mix in shallow wetlands located near the mouth of a river.

Euryhaline: able to live at a variety of salinities.

Eutrophication: process by which large additions of nutrients causes an overgrowth of algae and subsequent depletion of oxygen.

Evaporate: to change from liquid to vapor.

(F)

Fjords: a glacial trough valley now flooded with seawater to create a steep-walled inlet.

Food chain: a representation of the flow of energy between producers, consumers, and decomposers.

Food web: a representation of the linkages between food chains in a community.

Foreshore: the area between mean low water and mean high water.

Frontal dune: the dune closest to the water's edge.

(G)

Gastropod: one of a class of mollusks that includes the snails and nudibranchs.

Geologic time: the total time involved since formation of the earth to the present time. It spans millions or billions of years in the past.

Gill arch: the bone structure in the throat of fish that contains the gill rakers and filaments.

Gill raker: bony, finger-like projection in the throat of fish, used for food retention in some species

Gravity: the force of attraction between all masses in the universe; especially the attraction of the earth's mass for bodies near its surface.

Groundwater: water contained below ground in soil and rock.

(H)

Habitat: the place where an organism lives.

Haul-out: an area on the shore where marine mammals rest.

Herbivore: an animal that eats plants.

High marsh: the area of the marsh flooded infrequently by the high tides associated with new and full moon.

Human impact: impacts arising from human activity; often referring to negative impacts on the environment.

Hypothesis: a scientific idea about how something works, before the idea has been tested. Scientists do experiments to test a hypothesis and see if the hypothesis is correct.

Hypoxia (hypoxic): very low oxygen levels.

(I)

Infauna: organisms living between the grains of sand or mud.

Isopods: aquatic crustaceans with flat, oval body and seven pairs of legs.

Intertidal: estuary habitat flooded by high tide waters only.

Invasive species: non-native species of plants or animals that out-compete native species in a specific habitat.

Invertebrate: an animal that does not have a backbone; such as snails, worms, and insects.

(J)

(L)

Light: energy source used by plants to form carbohydrates, an important abiotic factor.

Low marsh: the area of marsh flooded twice daily by tides and dominated by Spartina alterniflora in Gulf of Maine region.

(M)

Macroalgae: large multicellular algae (green red and brown varieties).

Mangrove: tree species that grow in non-freezing estuaries. There are about 12 species though the black, red, and white are most common.

Maritime forest: forest dominated by pitch pine and located on the mainland side of a barrier beach or island.

Marshes: soft wet land usually characterized by grasses.

Mesohaline: intermediate levels of salinity, about 15ppt.

Metadata: the reference information about how the data is collected.

Migration (migratory): the movement of living organisms from one biome to another, commonly with changing seasons.

Mobile epibenthos: bottom-dwelling animals that move on top of sediments: crabs, shrimp, snails, amphipods, isopods.

Mollusks: soft bodied, shelled animals such as clams, oysters, nudibraches and octopi (the latter two have either small remnant shell within their bodies or an embryonic shell).

Monitoring (environmental monitoring): sampling of environment (air, water, soil, vegetation, animals) that is compared with baseline samples to see if any changes have occurred.

Monitoring station: an instrument that makes *in situ* measurements in the environment.

Mudflat: part of benthic (bottom) zone exposed at low tide and comprised of extremely fine sediments.

Mutualism: form of relationship in which both species involved gain from the interaction (example: lichen).

(N)

National Estuarine Research Reserve System: network of 27 protected areas established for long-term research, education and coastal stewardship authorized as part of the Coastal Zone Management (CZM) Act of 1972, which called for the establishment of a network of estuaries that represent different biogeographical regions of the United States.

Natural selection: the differential survival and/or reproduction of individuals within a population based on hereditary characteristics.

Neap tides: average tides that occur between full and new moons.

Nekton: all aquatic animals that can swim through the water against currents: marine mammals, fish, squid and some crustaceans.

Niche: the role of a species within a community.

No-take zones: aquatic or coastal areas in which all extractive activities (such as fishing) are prohibited.

Non-point source pollution: water pollution arising from indistinct sources such as petroleum products from roadways or pesticides from farmland.

Nursery: term used colloquially to refer to estuaries. Many fish species are dependent on estuaries for part of their lives.

Nutrients: substances required by organisms in order to grow and survive such as nitrogen and phosphorus.

Nutrient cycle: natural processes that recycle nutrients in various forms from the environment, to organisms and then back to the environment. Also called biogeochemical cycle.

(O)

Oligohaline: low salinity areas, 0-15 ppt.

Omnivores: animals that feed at several levels of food web; diet includes a mix of living and/or dead plants and animals.

Organic matter: materials and debris that originated as living plants or animals.

Organism: a living thing, such as animal, plant or micro-organism, that is capable of reproduction, growth and maintenance.

Oxygen: used in respiration, the process in which organisms release stored chemical energy.

Oxygen content: often referring to the oxygen content of water. The amount of oxygen dissolved in a given volume of water at a particular temperature and pressure.

(P)

Panne: small pond or pool in the salt marsh.

Parameter: the thing that is being measured.

Parasitism: similar to predation in that one species benefits from the relationship and the other is harmed; differs from predation in that parasitism generally not fatal to adversely affected organism.

Peat: soil in marsh composed of partially decayed moisture-absorbing plant matter.

Pelagic: of or in the open ocean or open water; in the water column.

Petroleum derivatives: toxic pollutants from crude oil products; mixture of hydrocarbons, which are organic solvents.

Photosynthesis: process of using energy in sunlight to convert water and carbon dioxide into carbohydrates and oxygen.

Phytoplankton: floating plants or plant-like photosynthetic single cellular organisms.

Pioneer species: plant species that first invades unvegetated area.

Plankton: free-floating organisms drifting in water, unable to swim against currents.

Point source pollution: pollution from a clearly defined, localized source such as a sewage outfall.

Pollution: contamination of natural environment.

Polyhaline: high salinity about 30-335 ppt.

Polyps: often refered to as coral polyps. A small individual coral animal with a tube-shaped body and a mouth surrounded by tentacles.

Population: all the individuals of a particular species within a defined area.

Precipitation: rain, snow, sleet, freezing rain, mist.

Predation (predatory): the killing and/or consumption of living organisms by other living organisms.

Primary dune: foredune; dune closest to water's edge.

Producer: autotroph; organism that creates energy-rich compounds from sunlight (through photosynthesis) or certain chemicals (through chemosynthesis); first level in any food web; in estuarine systems, most abundant producers are phytoplankton.

Productive ecosystem: a biological system that efficiently converts energy into growth and production.

Protists: often unicellular but they can be multi-cellular or colonial the organisms in this Kingdom have characteristics of plants, animals and fungi and contains most algae.

(R)

Recreational fishing: any fishing for which the primary motive is leisure rather than profit; fishing for pleasure.

Reef: chain or string of coral, oysters, rocks or other hard substrate.

Research: systematic investigation to establish facts.

Resource: entity (e.g., food, light, water, space) that an organism uses or consumes during its lifetime.

Respiration: process that, using oxygen, releases stored chemical energy to power an organism’s life processes; opposite reaction of photosynthesis.

Response: ecological responses are behavioral and physical changes that happen during the lifetime of a single organism and increase individual's chance of survival as opposed to evolutionary adaptation, which takes place over multiple generations and is a result of a change in the species genetic makeup.

Restoration: make physical changes in a destroyed or impaired habitat that returns a site to the type of habitat it was prior to human made impacts.

Riparian zone: the land and vegetation bordering flowing or standing water such as streams, rivers, lakes and ponds.

Rock cycle: also called the geologic cycle, the rock cycle is a fundamental concept in geology that describes the dynamic transitions through geologic time among the three main rock types: sedimentary, metamorphic, and igneous.

Runoff: precipitation that drains into a water body from the surface of the surrounding land.

(S)

Salinity: the concentration of salts dissolved in salt water.

Salts: most commonly NaCl or table salt but includes other salts such as MgCl2.

Salt marsh: wetland flooded regularly by tidal, brackish water.

Saltwater intrusion: the invasion of freshwater bodies by denser salt water.

Sandflat: area of bottom of aquatic system that is exposed by low tides and composed of sand - particles of sediment larger than those of mud.

Scientific method: the steps necessary for scientific investigation including 1) identify a problem you would like to solve, 2) formulate a hypothesis, 3) test the hypothesis, 4) collect and analyze the data, 5) make conclusions.

Sea level rise: long-term increases in mean sea level. The expression is popularly applied to anticipated sea level changes due to the greenhouse effect and associated global warming.

Sediment: particles deposited by wind or water.

Sedimentary rock: rock that is formed by the consolidation of sediment particles or of the remains of plants and animals.

Sessile: permanently attached or fixed; not free-moving.

Space: resource needed by all organisms; most pronounced need by organisms that require substrate.

Spawn: to deposit sperm or eggs into the water (fish reproduction).

Speciation: formation of new species through natural selection; occurs when selective force is intense; accounts for diversity of living things on planet today.

Species: a classification of related organisms that can freely interbreed.

Spring tides: extreme high and low tides that occur about twice a month, with the full and new moons.

Sublittoral zone: portion of rocky shore always submerged.

Substrate: the surface on which an organism grows.

Subtidal: area usually flooded near edge of tidal waters.

Succession: progressive replacement of populations in a habitat.

Supratidal: occaisionally flooded by very high or storm tides.

Surface water: water in streams, brooks, rivers, ponds and lakes, etc.

Swash zone: part of foreshore washed by waves.

Synthetic compounds: manufactured compounds.

System-Wide Monitoring Program (SWMP): pronounced "swamp". The monitoring program of the ational Estuarine Research Reserve System which tracks short-term variability and long-term changes in estuarine waters to understand how human activities and natural events can change ecosystems. This program measures physical and chemical water quality indicators, nutrients and the impacts of weather on estuaries. As the program expands, plans include adding a biological monitoring component and tracking changes in land use through remote sensing.

(T)

Tectonic estuaries: land flooded by sea due to subsidence, not sea-level rise.

Temperature: important abiotic factor affecting distribution and abundance of organisms; influences metabolic rate and affects rates of growth and reproduction.

Tidal height: difference between water level at high tide and mean sea level, the average height of the ocean.

Tidal range: difference between high and low tide.

Tides: periodic rise and fall of ocean waters due to gravitational pull of sun and moon, and rotation of earth.

Tolerant: capable of withstanding effects. Often refered to as the ability of speicies to withstand variabilities of their environment.

Trophic level (trophic): level in a food chain, e.g., producer, primary consumer, secondary consumer, tertiary consumer.

(U)

Uplands: lands lying above the reaches of the highest high tides.

(V)

Vertical stratification: laying of fresh water on top of salt water, also known as “salt wedge” effect; occurs when the fresh and salt water is not vigorously mixed together by turbulence.

(W)

Water: a molecule-composed compound of hydrogen and oxygen.

Water column: the area of water from the seafloor up to the water surface. The water column contains free swimming, or pelagic, organisms and plankton (tiny drifting and floating organisms). The water column is a part of all bays, sloughs, lagoons and coastal areas; and is therefore part of an estuary.

Water cycle: the recycling of water between the earth and the atmosphere.

Watersheds: area of land drained by a river or river system, lake or estuary.

Weathering: the process of physical disintegration and chemical decomposition whereby earth and rock materials are changed in color, texture, composition, firmness, or form upon exposure to the atmosphere.

Wetland: areas inundated or saturated by surface or ground water at a frequency and duration sufficient to support , and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions (US Army Corp of Engineers for Section 404 support of the 1977 Clean Water Act Amendments)

Wrack line: a string of debris stranded by last high tide; cast ashore seaweeds, isolated sources of food and shade support an important community of isopods and amphipods as well as providing food for birds.

(Z)

Zonation (zonal habitats): distribution of plants or animals arranged in zones or bands, caused by gradations of abiotic and/or biotic factors.

Zooplankton: animal or animal-like protists, small or microscopic, that drift with the currents, may be either herbivores or carnivores.

Pennsylvania Envirothon
2011 Current Issue – Salt & Fresh Water Estuaries
Required Resources

1. **2011 CI Salt & Fresh Water Estuaries**

   Resources cited for this document:

   a. National Ocean Service Education: Estuaries
   http://oceanservice.noaa.gov/education/tutorial_estuaries/welcome.html

   b. Estuaries 101
   http://www.estuaries.gov/estuaries.101/About/Home.aspx

   c. EPA – Voluntary Estuary Monitoring Manual: Chapter 2: Overview, covering the science, the problems, and the solution – March 2006

   d. Sea Grant Pennsylvania
   http://seagrant.psu.edu/seagindex.htm

2. **Clean Boating Tips** – Sea Grant Pennsylvania
3. **Pennsylvania's Bluff Recession and Setback Program** – Sea Grant Pennsylvania
4. **Living on Pennsylvania's Lake Erie Coast** – Sea Grant Pennsylvania
5. **Nonpoint Source Pollution** – Pennsylvania Lake Erie NEMO
6. **Land Use and Water Quality** – Pennsylvania Lake Erie NEMO
7. **Wetlands Protection and Agriculture** – PA Department of Environmental Protection
8. **The Pennsylvania Coastal Zone Management Program** – PA Department of Environmental Protection
9. **A Conservation Catalog**
10. **Discover the Salt Marsh**
11. **Chesapeake Bay Introduction to an Ecosystem**

Supplemental Resource for Teachers

1. Estuaries 101 Curriculum
   http://www.estuaries.gov/estuaries.101/About/Home.aspx