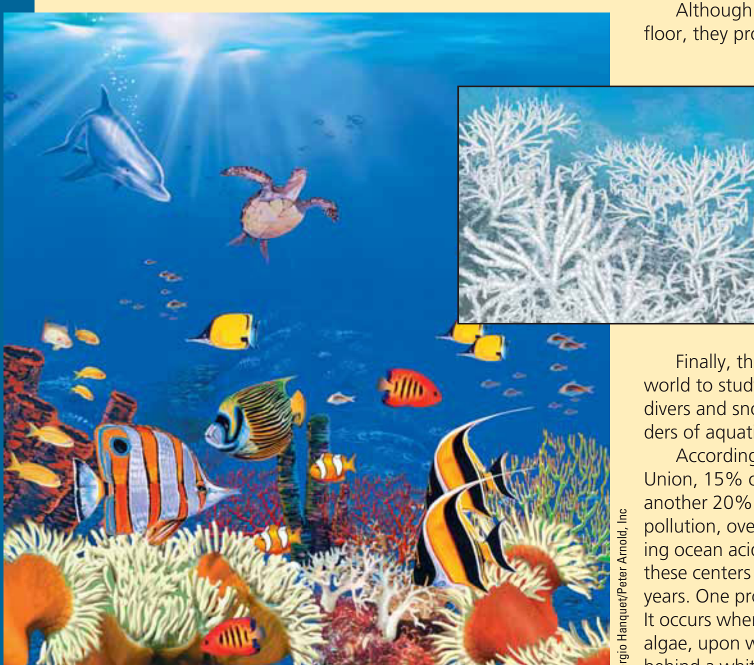
8 Aquatic Biodiversity

CORE CASE STUDY Why Should We Care about Coral Reefs?

Coral reefs form in clear, warm coastal waters of the tropics and subtropics (Figure 8-1, left). These stunningly beautiful natural wonders are among the world's oldest, most diverse, and most productive ecosystems. In terms of biodiversity, they are the marine equivalents of tropical rain forests.

Coral reefs are formed by massive colonies of tiny animals called *polyps* (close relatives of jellyfish). They slowly build reefs by secreting a protective crust of limestone (calcium carbonate) around their soft bodies. When the polyps die, their empty crusts remain behind as a platform for more reef growth. The resulting elaborate network of crevices, ledges, and holes serves as calcium carbonate "condominiums" for a variety of marine animals.



Sergio Hanquet/Peter Arnold, Inc

Figure 8-1 *A healthy coral reef* in the Red Sea covered by colorful algae (left) and a bleached coral reef that has lost most of its algae (right) because of changes in the environment (such as cloudy water or high water temperatures). With the colorful algae gone, the white limestone of the coral skeleton becomes visible. If the environmental stress is not removed and no other alga species fill the abandoned niche, the corals die. These diverse and productive ecosystems are being damaged and destroyed at an alarming rate.

Coral reefs are the result of a mutually beneficial relationship between the polyps and tiny single-celled algae called *zooxanthellae* ("zoh-ZAN-thel-ee") that live in the tissues of the polyps. In this example of mutualism (p. 106), the algae provide the polyps with food and oxygen through photosynthesis, and help to produce calcium carbonate, which forms the coral skeleton. Algae also give the reefs their stunning coloration. The polyps, in turn, provide the algae with a well-protected home and some of their nutrients.

Although coral reefs occupy only about 0.2% of the ocean floor, they provide important ecological and economic services. They help moderate atmospheric temperatures by removing CO_2 from the atmosphere, and they act as natural barriers that protect 15% of the world's coastlines from erosion caused by battering waves and storms. And they provide habitats for one-quarter of all marine organisms. Economically, coral reefs produce about one-tenth of the global fish catch—one-fourth of the catch in developing countries—and they provide jobs and building materials for some of the world's poorest countries. Coral reefs also support important fishing and tourism industries.

Finally, these biological treasures give us an underwater world to study and enjoy. Each year, more than 1 million scuba divers and snorkelers visit coral reefs to experience these wonders of aquatic biodiversity.

According to a 2005 report by the World Conservation Union, 15% of the world's coral reefs have been destroyed and another 20% have been damaged by coastal development, pollution, overfishing, warmer ocean temperatures, increasing ocean acidity, and other stresses. And another 25–33% of these centers of aquatic biodiversity could be lost within 20–40 years. One problem is *coral bleaching* (Figure 8-1, upper right). It occurs when stresses such as increased temperature cause the algae, upon which corals depend for food, to die off, leaving behind a white skeleton of calcium carbonate. Another threat is the increasing acidity of ocean water as it absorbs some of the CO_2 produced by the burning of carbon-containing fossils fuels. The CO_2 reacts with ocean water to form a weak acid, which can slowly dissolve the calcium carbonate that makes up the corals.

The degradation and decline of these colorful oceanic sentinels should serve as a warning about threats to the health of the oceans, which provide us with crucial ecological and economic services.

Key Questions and Concepts

8-1 What is the general nature of aquatic systems?

CONCEPT 8-1A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface with oceans dominating the planet.

CONCEPT 8-1B The key factors determining biodiversity in aquatic systems are temperature, dissolved oxygen content, availability of food, and availability of light and nutrients necessary for photosynthesis.

8-2 Why are marine aquatic systems important?

CONCEPT 8-2 Saltwater ecosystems are irreplaceable reservoirs of biodiversity and provide major ecological and economic services.

8-3 How have human activities affected marine ecosystems?

CONCEPT 8-3 Human activities threaten aquatic biodiversity and disrupt ecological and economic services provided by saltwater systems.

8-4 Why are freshwater ecosystems important?

CONCEPT 8-4 Freshwater ecosystems provide major ecological and economic services and are irreplaceable reservoirs of biodiversity.

8-5 How have human activities affected freshwater ecosystems?

CONCEPT 8-5 Human activities threaten biodiversity and disrupt ecological and economic services provided by freshwater lakes, rivers, and wetlands.

Note: Supplements 2 (p. S4), 4 (p. S20), 5 (p. S31), 7 (p. S46), 9 (p. S53), and 13 (p. S78) can be used with this chapter.

If there is magic on this planet,
it is contained in water.

LOREN EISLEY

8-1 What Is the General Nature of Aquatic Systems?

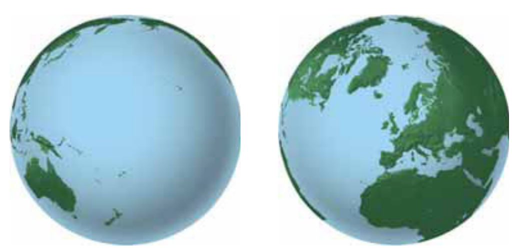
▶ **CONCEPT 8-1A Saltwater and freshwater aquatic life zones cover almost three-fourths of the earth's surface with oceans dominating the planet.**

▶ **CONCEPT 8-1B The key factors determining biodiversity in aquatic systems are temperature, dissolved oxygen content, availability of food, and availability of light and nutrients necessary for photosynthesis.**

Most of the Earth Is Covered with Water

When viewed from a certain point in outer space, the earth appears to be almost completely covered with water (Figure 8-2). Saltwater covers about 71% of the earth's surface, and freshwater occupies roughly another 2.2%. Yet, in proportion to the entire planet, it all amounts to a thin and precious film of water.

Although the *global ocean* is a single and continuous body of water, geographers divide it into four large areas—the Atlantic, Pacific, Arctic, and Indian Oceans—separated by the continents. The largest ocean is the Pacific, which contains more than half of the earth's water and covers one-third of the earth's surface.



Ocean hemisphere   Land–ocean hemisphere

Figure 8-2 *The ocean planet.* The salty oceans cover 71% of the earth's surface. Almost all of the earth's water is in the interconnected oceans, which cover 90% of the planet's mostly ocean hemisphere (left) and half of its land–ocean hemisphere (right). Freshwater systems cover less than 2.2% of the earth's surface (**Concept 8-1A**).

The aquatic equivalents of biomes are called **aquatic life zones.** The distribution of many aquatic organisms is determined largely by the water's *salinity*—the amounts of various salts such as sodium chloride (NaCl) dissolved in a given volume of water. As a result, aquatic life zones are classified into two major types: **saltwater** or **marine** (oceans and their accompanying estuaries, coastal wetlands, shorelines, coral reefs, and mangrove forests) and **freshwater** (lakes,

Figure 8-3 **Natural capital:** distribution of the world's major saltwater oceans, coral reefs, mangroves, and freshwater lakes and rivers. **Question:** Why do you think most coral reefs lie in the southern hemisphere?

rivers, streams, and inland wetlands). Although some systems such as estuaries are a mix of saltwater and freshwater, we classify them as marine systems for purposes of discussion.

Figure 8-3 shows the distribution of the world's major oceans, coral reefs, mangroves, lakes, and rivers. These aquatic systems play vital roles in the earth's biological productivity, climate, biogeochemical cycles, and biodiversity, and they provide us with fish, shellfish, minerals, recreation, transportation routes, and many other economically important goods and services.

Most Aquatic Species Live in Top, Middle, or Bottom Layers of Water

Saltwater and freshwater life zones contain several major types of organisms. One such type consists of weakly swimming, free-floating **plankton,** which can be divided into three groups, the first of which is *phytoplankton* ("FY-toe-plank-ton," Greek for "drifting plants"; see bottom of Figure 3-14, p. 63), which includes many types of algae. They and various rooted plants near shorelines are primary producers that support most aquatic food webs. See *The Habitable Planet,* Videos 2 and 3, at **www.learner.org/resources/series209.html**.

The second group is *zooplankton* ("ZOH-uh-plank-ton," Greek for "drifting animals"; see bottom of Figure 3-14, p. 63). They consist of primary consumers (herbivores) that feed on phytoplankton and secondary consumers that feed on other zooplankton. They range from single-celled protozoa to large invertebrates such as jellyfish.

A third group consists of huge populations of much smaller plankton called *ultraplankton.* These extremely small photosynthetic bacteria may be responsible for 70% of the primary productivity near the ocean surface.

A second major type of organisms is **nekton,** strongly swimming consumers such as fish, turtles, and whales. The third type, **benthos,** consists of bottom dwellers such as oysters, which anchor themselves to one spot; clams and worms, which burrow into the sand or mud; and lobsters and crabs, which walk about on the sea floor. A fourth major type is **decomposers** (mostly bacteria), which break down organic compounds in the dead bodies and wastes of aquatic organisms into nutrients that can be used by aquatic primary producers.

Most forms of aquatic life are found in the *surface, middle,* and *bottom* layers of saltwater and freshwater systems, which we explore later in this chapter. In most aquatic systems, the key factors determining the types and numbers of organisms found in these layers are *temperature, dissolved oxygen content, availability of food,* and *availability of light and nutrients required for photosynthesis,* such as carbon (as dissolved CO_2 gas), nitrogen (as NO_3^-), and phosphorus (mostly as PO_4^{3-}) (**Concept 8-1B**).

In deep aquatic systems, photosynthesis is largely confined to the upper layer—the *euphotic* or *photic* zone, through which sunlight can penetrate. The depth of the euphotic zone in oceans and deep lakes can be reduced when the water is clouded by excessive algal growth (algal blooms) resulting from nutrient overloads. This cloudiness, called **turbidity,** can occur naturally, such as from algal growth, or can result from disturbances such as clearing of land, which causes silt to flow into bodies of water. This is one of the problems plaguing coral reefs (**Core Case Study**), as excessive turbidity due to silt runoff prevents photosynthesis and causes the corals to die.

In shallow systems such as small open streams, lake edges, and ocean shorelines, ample supplies of nutrients for primary producers are usually available. By contrast, in most areas of the open ocean, nitrates, phosphates, iron, and other nutrients are often in short supply, and this limits net primary productivity (NPP) (Figure 3-16, p. 64).

8-2 Why Are Marine Aquatic Systems Important?

CONCEPT 8-2 Saltwater ecosystems are irreplaceable reservoirs of biodiversity and provide major ecological and economic services.

Oceans Provide Important Ecological and Economic Resources

Oceans provide enormously valuable ecological and economic services (Figure 8-4). One estimate of the combined value of these goods and services from all marine coastal ecosystems is over $12 trillion per year, nearly equal to the annual U.S. gross domestic product.

As land dwellers, we have a distorted and limited view of the blue aquatic wilderness that covers most of the earth's surface. We know more about the surface of the moon than about the oceans. According to aquatic scientists, the scientific investigation of poorly understood marine and freshwater aquatic systems could yield immense ecological and economic benefits.

Marine aquatic systems are huge reservoirs of biodiversity. They include many different ecosystems, which host a great variety of species, genes, and biological and chemical processes, thus sustaining four major components of the earth's biodiversity (Figure 4-2, p. 79). Marine life is found in three major *life zones:* the coastal zone, open sea, and ocean bottom (Figure 8-5, p. 166).

RESEARCH FRONTIER

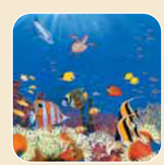
Discovering, cataloging, and studying the huge number of unknown aquatic species and their interactions. See **academic .cengage.com/biology/miller**.

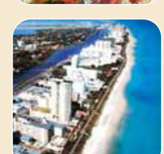
The **coastal zone** is the warm, nutrient-rich, shallow water that extends from the high-tide mark on

NATURAL CAPITAL

Marine Ecosystems

Ecological Services	Economic Services
Climate moderation	Food
CO_2 absorption	Animal and pet feed
Nutrient cycling	Pharmaceuticals
Waste treatment	Harbors and transportation routes
Reduced storm impact (mangroves, barrier islands, coastal wetlands)	Coastal habitats for humans
Habitats and nursery areas	Recreation
Genetic resources and biodiversity	Employment
Scientific information	Oil and natural gas
	Minerals
	Building materials





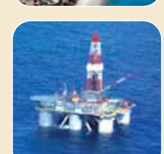


Figure 8-4 Major ecological and economic services provided by marine systems (**Concept 8-2**). **Question:** Which two ecological services and which two economic services do you think are the most important? Why?

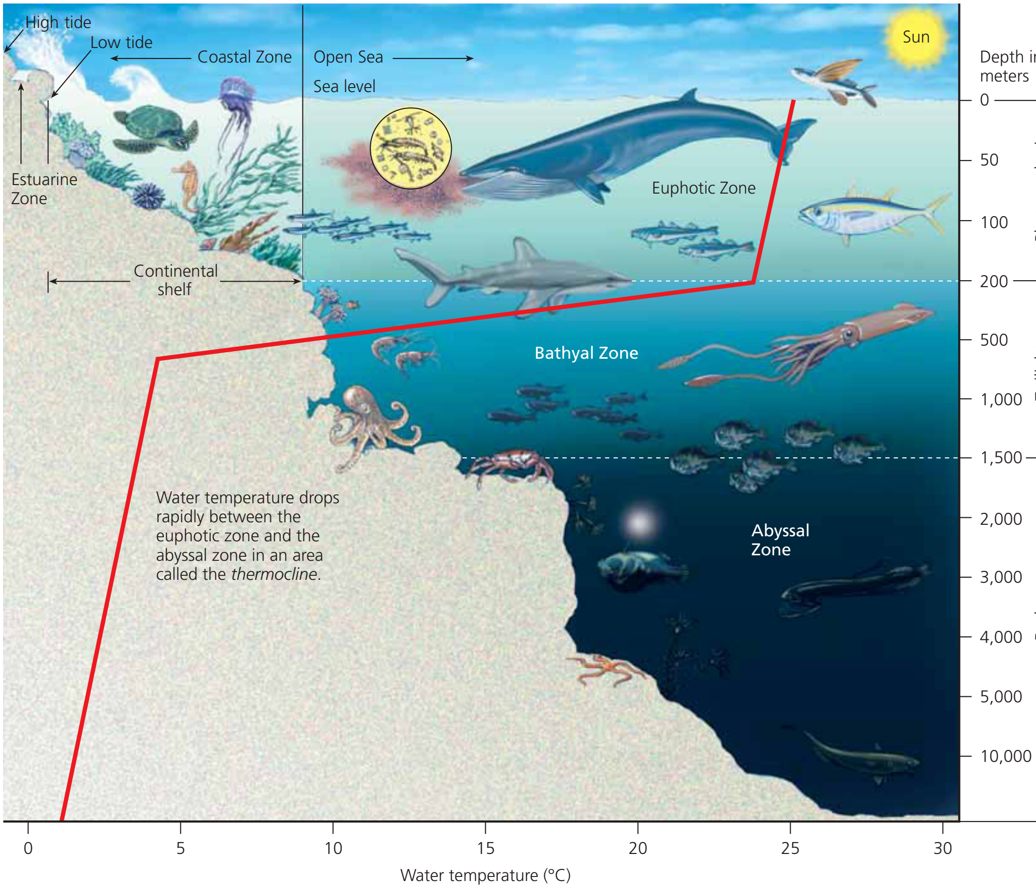


Figure 8-5 **Natural capital:** major life zones and vertical zones (not drawn to scale) in an ocean. Actual depths of zones may vary. Available light determines the euphotic, bathyal and abyssal zones. Temperature zones also vary with depth, shown here by the red curve. **Question:** How is an ocean like a rain forest? (*Hint:* see Figure 7-17, p. 156.)

land to the gently sloping, shallow edge of the *continental shelf*. It makes up less than 10% of the world's ocean area but contains 90% of all marine species and is the site of most large commercial marine fisheries. Most coastal zone aquatic systems, such as estuaries, coastal wetlands, mangrove forests, and coral reefs, have a high NPP per unit of area (Figure 3-16, p. 64). This is the result of the zone's ample supplies of sunlight and plant nutrients that flow from land and are distributed by wind and ocean currents. Here, we look at some of these systems in more detail.

Estuaries and Coastal Wetlands Are Highly Productive

Estuaries are where rivers meet the sea (Figure 8-6). They are partially enclosed bodies of water where seawater mixes with freshwater as well as nutrients and pollutants from streams, rivers, and runoff from the land.

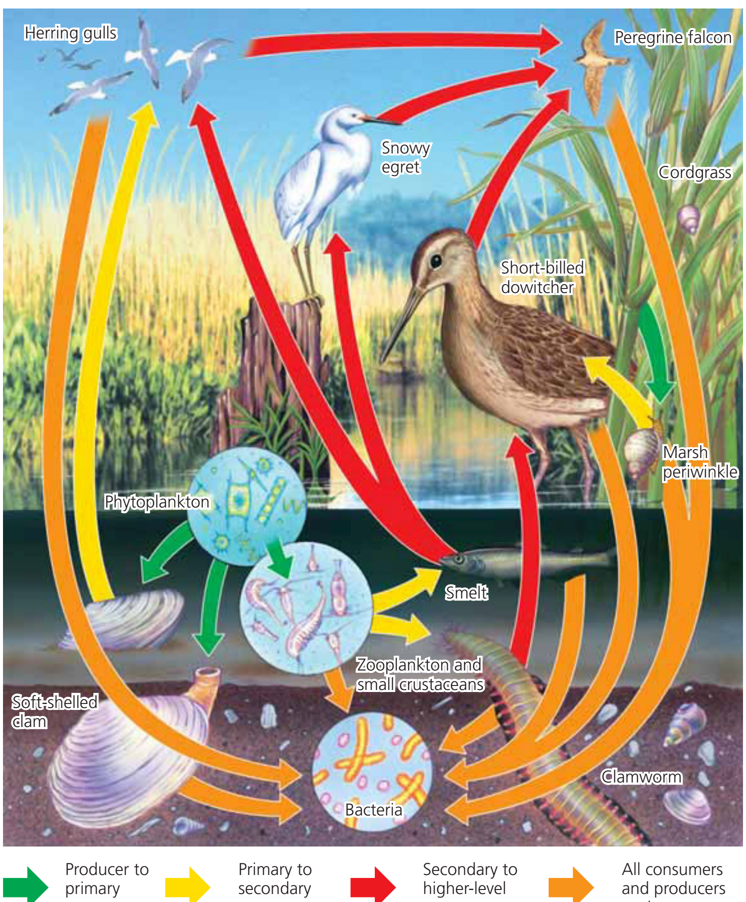
Estuaries and their associated **coastal wetlands**—coastal land areas covered with water all or part of the year—include river mouths, inlets, bays, sounds, and salt marshes in temperate zones (Figure 8-7), and mangrove forests in tropical zones (Figure 8-3). They are some of the earth's most productive ecosystems because of high nutrient inputs from rivers and nearby land, rapid circulation of nutrients by tidal flows, and ample sunlight penetrating the shallow waters.

Seagrass beds are another component of coastal marine biodiversity. They consist of at least 60 species of plants that grow underwater in shallow marine and estuarine areas along most continental coastlines. These highly productive and physically complex systems support a variety of marine species. They also help stabilize shorelines and reduce wave impacts.

Life in these coastal ecosystems is harsh. It must adapt to significant daily and seasonal changes in tidal and river flows, water temperatures and salinity, and runoff of eroded soil sediment and other pollutants from the land. Because of these stresses, despite their

NASA

Figure 8-6 View of an *estuary* from space. The photo shows the sediment plume (turbidity caused by runoff) at the mouth of Madagascar's Betsiboka River as it flows through the estuary and into the Mozambique Channel. Because of its topography, heavy rainfall, and the clearing of forests for agriculture, Madagascar is the world's most eroded country.



SuperStock

Figure 8-7 Some components and interactions in a *salt marsh ecosystem* in a temperate area such as the United States. When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale. The photo shows a salt marsh in Peru.

Figure 8-8 Mangrove forest in Daintree National Park in Queensland, Australia. The tangled roots and dense vegetation in these coastal forests act like shock absorbers to reduce damage from storms and tsunamis. They also provide a highly complex habitat for a diversity of invertebrates and fishes.

Theo Allofs/Visuals Unlimited

productivity, some coastal ecosystems have low plant diversity, composed of a few species that can withstand the daily and seasonal variations.

Mangrove forests are the tropical equivalent of salt marshes. They are found along some 70% of gently sloping sandy and silty coastlines in tropical and subtropical regions, especially Southeast Asia (Figure 8-3). The dominant organisms in these nutrient-rich coastal forests are mangroves—69 different tree species that can grow in salt water. They have extensive root systems that often extend above the water, where they can obtain oxygen and support the trees during periods of changing water levels (Figure 8-8).

These coastal aquatic systems provide important ecological and economic services. They help to maintain water quality in tropical coastal zones by filtering toxic pollutants, excess plant nutrients, and sediments, and by absorbing other pollutants. They provide food, habitats, and nursery sites for a variety of aquatic and terrestrial species. They also reduce storm damage and coastal erosion by absorbing waves and storing excess water produced by storms and tsunamis. Historically, they have sustainably supplied timber and fuelwood to coastal communities.

Loss of mangroves can lead to polluted drinking water, caused by inland intrusion of saltwater into aquifers that are used to supply drinking water. Despite their ecological and economic importance, in 2008, the U.N. Food and Agriculture Organization estimated that between 1980 and 2005 at least one-fifth of the world's mangrove forests were lost mostly because of human coastal development.

Rocky and Sandy Shores Host Different Types of Organisms

The gravitational pull of the moon and sun causes *tides* to rise and fall about every 6 hours in most coastal areas. The area of shoreline between low and high tides is called the **intertidal zone.** Organisms living in this zone must be able to avoid being swept away or crushed by waves, and must deal with being immersed during high tides and left high and dry (and much hotter) at low tides. They must also survive changing levels of salinity when heavy rains dilute saltwater. To deal with such stresses, most intertidal organisms hold on to something, dig in, or hide in protective shells.

On some coasts, steep *rocky shores* are pounded by waves. The numerous pools and other habitats in their intertidal zones contain a great variety of species that occupy different niches in response to daily and seasonal changes in environmental conditions such as temperature, water flows, and salinity (Figure 8-9, top).

Other coasts have gently sloping *barrier beaches,* or *sandy shores,* that support other types of marine organisms (Figure 8-9, bottom). Most of them keep hidden from view and survive by burrowing, digging, and tunneling in the sand. These sandy beaches and their adjoining coastal wetlands are also home to a variety of shorebirds that feed in specialized niches on crustaceans, insects, and other organisms (Figure 4-13, p. 93). Many of these species also live on *barrier islands*—low, narrow, sandy islands that form offshore, parallel to some coastlines.

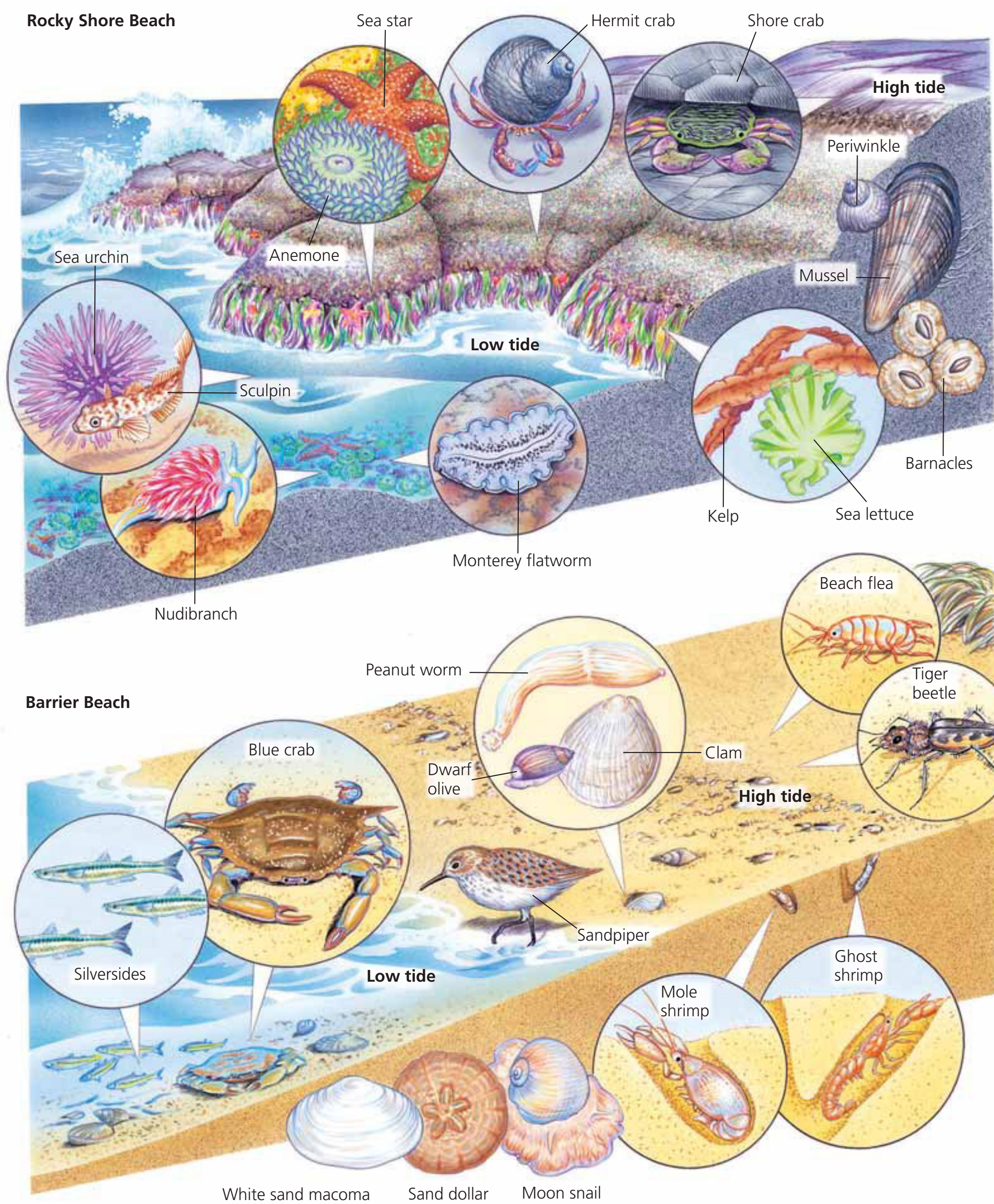


Figure 8-9 *Living between the tides.* Some organisms with specialized niches found in various zones on rocky shore beaches (top) and barrier or sandy beaches (bottom). Organisms are not drawn to scale.

Undisturbed barrier beaches generally have one or more rows of natural sand dunes in which the sand is held in place by plant roots (Figure 8-10, p. 170). These dunes are the first line of defense against the ravages of the sea. Such real estate is so scarce and valuable that coastal developers frequently remove the protective dunes or build behind the first set of dunes and cover them with buildings and roads. Large storms can then flood and even sweep away seaside buildings and severely erode the sandy beaches. Some people incorrectly call these human-influenced events "natural disasters."

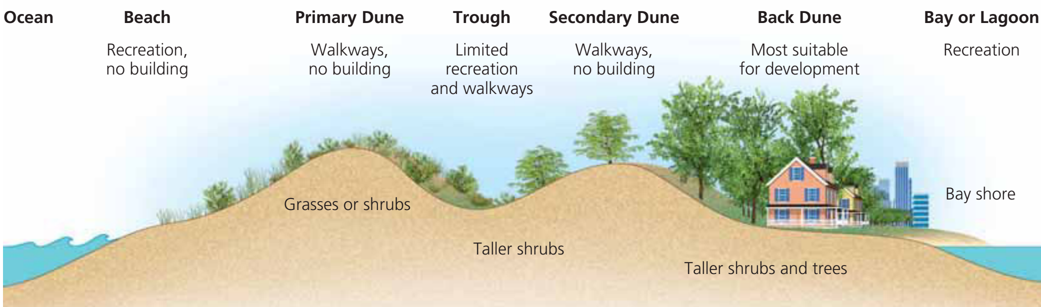


Figure 8-10 *Primary and secondary dunes* on gently sloping sandy barrier beaches help protect land from erosion by the sea. The roots of grasses that colonize the dunes hold the sand in place. Ideally, construction is allowed only behind the second strip of dunes, and walkways to the ocean beach are built so as not to damage the dunes. This helps to preserve barrier beaches and to protect buildings from damage by wind, high tides, beach erosion, and flooding from storm surges. Such protection is rare in some coastal areas because the short-term economic value of oceanfront land is considered much higher than its long-term ecological value. Rising sea levels from global warming may put many barrier beaches under water by the end of this century. **Question:** Do you think that the long- and short-term ecological values of oceanfront dunes outweigh the short-term economic value of removing them for coastal development? Explain.

Coral Reefs Are Amazing Centers of Biodiversity

CORE CASE STUDY

As we noted in the **Core Case Study**, coral reefs are among the world's oldest, most diverse, and productive ecosystems (Figure 8-1 and Figure 4-10, left, p. 89). These amazing centers of aquatic biodiversity are the marine equivalents of tropical rain forests, with complex interactions among their diverse populations of species (Figure 8-11). Coral reefs provide homes for one-fourth of all marine species.

The Open Sea and Ocean Floor Host a Variety of Species

The sharp increase in water depth at the edge of the continental shelf separates the coastal zone from the vast volume of the ocean called the **open sea.** Primarily on the basis of the penetration of sunlight, this deep blue sea is divided into three *vertical zones* (see Figure 8-5). But temperatures also change with depth and can be used to define zones that help to determine species diversity in these layers (Figure 8-5, red curve).

The *euphotic zone* is the brightly lit upper zone where drifting phytoplankton carry out about 40% of the world's photosynthetic activity (see *The Habitable Planet,* Video 3, at **www.learner.org/resources/series209.html**). Nutrient levels are low (except around upwellings, Figure 7-2, p. 142), and levels of dissolved oxygen are high. Large, fast-swimming predatory fishes such as swordfish, sharks, and bluefin tuna populate this zone.

The *bathyal zone* is the dimly lit middle zone, which, because it gets little sunlight, does not contain photosynthesizing producers. Zooplankton and smaller fishes, many of which migrate to feed on the surface at night, populate this zone.

The deepest zone, called the *abyssal zone,* is dark and very cold; it has little dissolved oxygen. Nevertheless, the deep ocean floor is teeming with life—enough to be considered a major life zone—because it contains enough nutrients to support a large number of species, even though there is no sunlight to support photosynthesis.

Most organisms of the deep waters and ocean floor get their food from showers of dead and decaying organisms—called *marine snow*—drifting down from upper lighted levels of the ocean. Some of these organisms, including many types of worms, are *deposit feeders,* which take mud into their guts and extract nutrients from it. Others such as oysters, clams, and sponges are *filter feeders,* which pass water through or over their bodies and extract nutrients from it.

Average primary productivity and NPP per unit of area are quite low in the open sea. However, because open sea covers so much of the earth's surface, it makes the largest contribution to the earth's overall NPP. Also, NPP is much higher in some open sea areas where winds, ocean currents, and other factors cause water to rise from the depths to the surface. These *upwellings* bring nutrients from the ocean bottom to the surface for use by producers (Figure 7-2, p. 142).

In 2007, a team of scientists led by J. Craig Venter released a report that dramatically challenged scientists' assumptions about biodiversity in the open sea. After sailing around the world and spending 2 years collecting data, they found that the open sea contains many more bacteria, viruses, and other microbes than scientists had previously assumed.

CENGAGENOW™ Learn about ocean provinces where all ocean life exists at CengageNOW™.

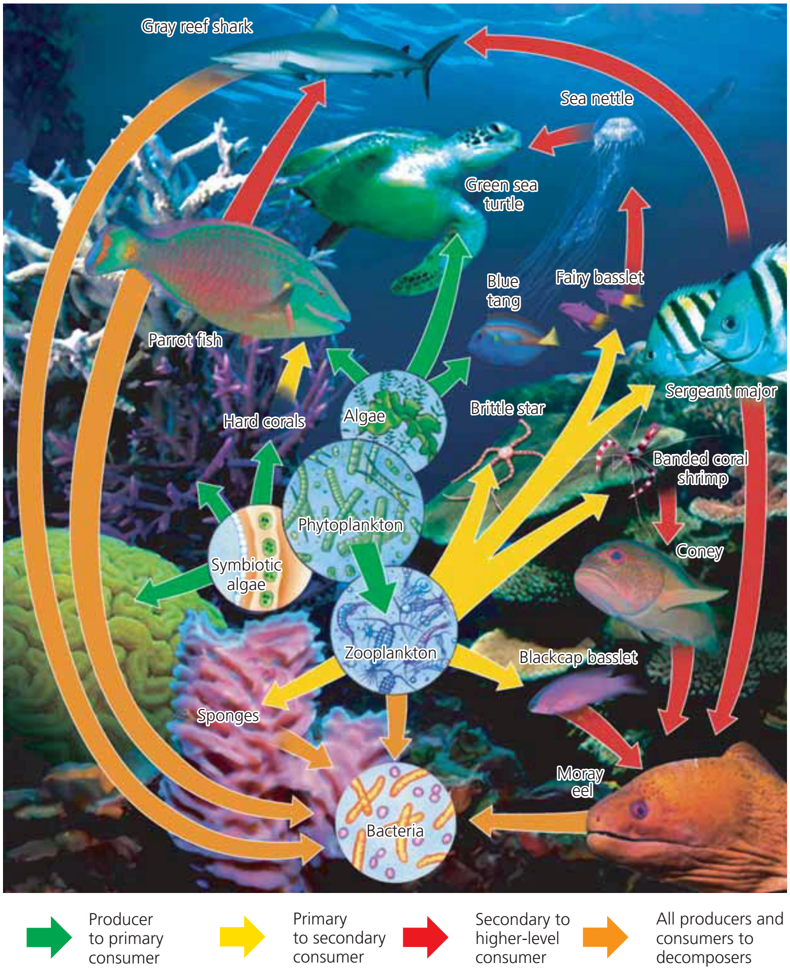


Figure 8-11 Natural capital: some components and interactions in a *coral reef ecosystem.* When these organisms die, decomposers break down their organic matter into minerals used by plants. Colored arrows indicate transfers of matter and energy between producers, primary consumers (herbivores), secondary or higher-level consumers (carnivores), and decomposers. Organisms are not drawn to scale.

8-3 How Have Human Activities Affected Marine Ecosystems?

▶ **CONCEPT 8-3 Human activities threaten aquatic biodiversity and disrupt ecological and economic services provided by saltwater systems.**

Human Activities Are Disrupting and Degrading Marine Systems

Human activities are disrupting and degrading some ecological and economic services provided by marine aquatic systems, especially coastal wetlands, shorelines, mangrove forests, and coral reefs (**Concept 8-3**). (See *The Habitable Planet,* Video 9, at **www.learner.org/resources/series209.html**.) Thus, a single largely land-based species—humans—is increasingly threatening the biological diversity and ecosystem services provided by the oceans that cover about 71% of the earth's surface.

In 2008, the U.S. National Center for Ecological Analysis and Synthesis (NCEAS) used computer models

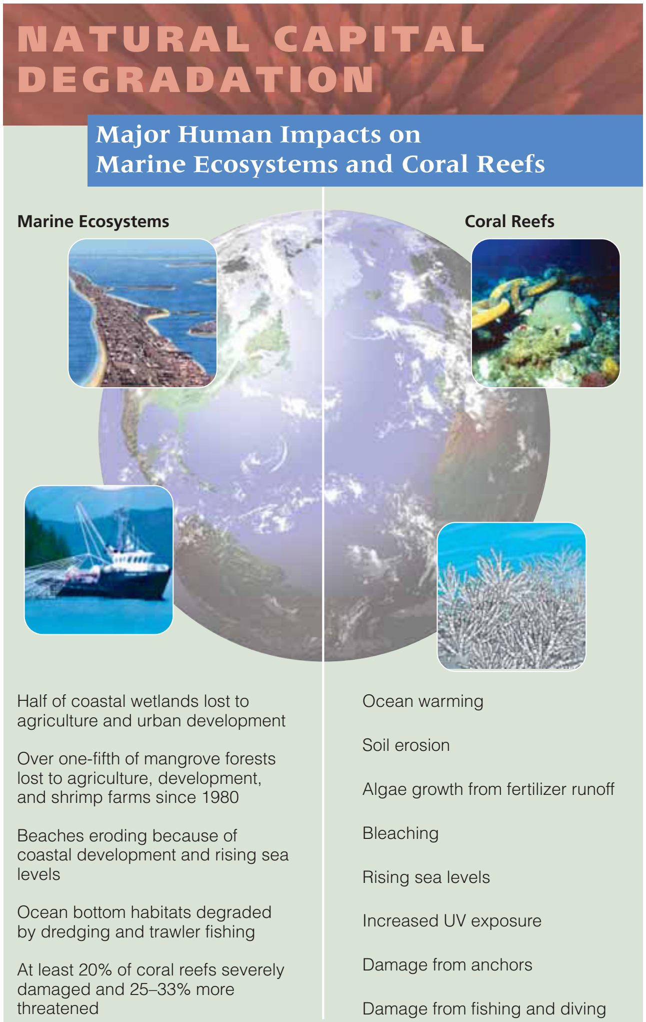


Figure 8-12 Major threats to marine ecosystems (left) and particularly coral reefs (right) resulting from human activities (**Concept 8-3**). **Questions:** Which two of the threats to marine ecosystems do you think are the most serious? Why? Which two of the threats to coral reefs do you think are the most serious? Why?

to analyze and provide the first-ever comprehensive map of the effects of 17 different types of human activities on the world's oceans. In this four-year study, the international team of scientists found that human activity has heavily affected 41% of the world's ocean area, with no area left completely untouched.

In their desire to live near the coast, people are destroying or degrading the natural resources and services (Figure 8-4) that make coastal areas so enjoyable and valuable. In 2006, about 45% of the world's population (including more than half of the U.S. population) lived along or near coasts. By 2040, up to 80% of the world's people are projected to be living in or near coastal zones.

Major threats to marine systems from human activities include:

- Coastal development, which destroys and pollutes coastal habitats (see *The Habitable Planet,* Video 5, at **www.learner.org/resources/series209.html**)
- Overfishing, which depletes populations of commercial fish species
- Runoff of nonpoint source pollution such as fertilizers, pesticides, and livestock wastes from the land (see *The Habitable Planet,* Videos 7 and 8, at **www.learner.org/resources/series209.html**)
- Point source pollution such as sewage from passenger cruise ships and spills from oil tankers
- Habitat destruction from coastal development and trawler fishing boats that drag weighted nets across the ocean bottom
- Invasive species, introduced by humans, that can deplete populations of native aquatic species and cause economic damage
- Climate change, enhanced by human activities, that could cause a rise in sea levels, which could destroy coral reefs and flood coastal marshes and coastal cities (see *The Habitable Planet,* Videos 7 and 8, at **www.learner.org/resources/series209.html**)
- Climate change from burning fossil fuels, which is also threatening marine ecosystems by warming the oceans and making them more acidic
- Pollution and degradation of coastal wetlands and estuaries (Case Study, below)

Figure 8-12 shows some of the effects of such human impacts on marine systems (left) and coral reefs (right). According to a 2007 study by O. Hoegh-Guldberg and 16 other scientists, unless we take action soon to significantly reduce carbon dioxide emissions, the oceans may become too acidic and too warm for most of the world's coral reefs to survive this century, and the important ecological and economic services they provide will be lost. We will examine some of these impacts more closely in Chapter 11.

RESEARCH FRONTIER

Learning more about harmful human impacts on marine ecosystems and how to reduce these impacts. See **academic.cengage.com/biology/miller**.

■ **CASE STUDY**

The Chesapeake Bay—an Estuary in Trouble

Since 1960, the Chesapeake Bay (Figure 8-13)—the largest estuary in the United States—has been in serious trouble from water pollution, mostly because of human activities. One problem is population growth. Between 1940 and 2007, the number of people living

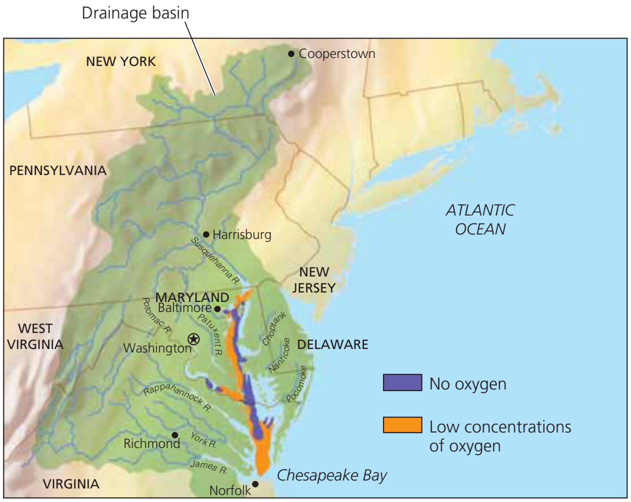


Figure 8-13 *Chesapeake Bay,* the largest estuary in the United States, is severely degraded as a result of water pollution from point and nonpoint sources in six states and from the atmospheric deposition of air pollutants.

in the Chesapeake Bay area grew from 3.7 million to 16.6 million. And the rate of population increase in the bay area has increased since 1990. With more than 450 people moving into the watershed each day, the population may soon reach 17 million.

The estuary receives wastes from point and nonpoint sources scattered throughout a huge drainage basin that includes 9 large rivers and 141 smaller streams and creeks in parts of six states (Figure 8-13). The bay has become a huge pollution sink because only 1% of the waste entering it is flushed into the Atlantic Ocean. It is also so shallow that people can wade through much of it.

Phosphate and nitrate levels have risen sharply in many parts of the bay, causing algal blooms and oxygen depletion. Commercial harvests of its once-abundant oysters, crabs, and several important fishes have fallen sharply since 1960 because of a combination of pollution, overfishing, and disease.

Point sources, primarily sewage treatment plants and industrial plants (often in violation of their discharge permits), account for 60% by weight of the phosphates. Nonpoint sources—mostly runoff of fertilizer and animal wastes from urban, suburban, and agricultural land and deposition from the atmosphere—account for 60% by weight of the nitrates. According to a 2004 study by the Chesapeake Bay Foundation, animal manure is the largest source of nitrates and phosphates from agricultural pollution.

In 1983, the United States implemented the Chesapeake Bay Program. In this ambitious attempt at *integrated coastal management,* citizens' groups, communities, state legislatures, and the federal government are working together to reduce pollution inputs into the bay. Strategies include establishing land-use regulations in the bay's six watershed states to reduce agricultural and urban runoff, banning phosphate detergents, upgrading sewage treatment plants, and monitoring industrial discharges more closely. In addition, wetlands are being restored and large areas of the bay are being replanted with sea grasses to help filter out nutrients and other pollutants.

A century ago, oysters were so abundant that they filtered and cleaned the Chesapeake's entire volume of water every 3 days. This important form of natural capital helped to remove excess nutrients and reduce algal blooms that decreased dissolved oxygen levels. Now the oyster population has been reduced to the point where this filtration process takes a year.

Officials in the states of Maryland and Virginia are evaluating whether to rebuild the Chesapeake's oyster population by introducing an Asian oyster that appears resistant to two parasites that have killed off many of the bay's native oysters. The Asian oysters grow bigger and faster and taste as good as native oysters. But introducing the nonnative Asian oyster is unpredictable and irreversible, and some researchers warn that this nonnative species may not help to clean the water, because it requires clean water in order to flourish.

The hard work on improving the water quality of the Chesapeake Bay has paid off. Between 1985 and 2000, phosphorus levels declined 27%, nitrogen levels dropped 16%, and grasses growing on the bay's floor have made a comeback. This is a significant achievement, given the increasing population in the watershed and the fact that nearly 40% of the nitrogen inputs come from the atmosphere.

There is still a long way to go, and a sharp drop in state and federal funding has slowed progress. During the summer of 2005, more than 40% of the bay had too little dissolved oxygen to support many kinds of aquatic life. And according to a 2006 report by the Chesapeake Bay Foundation, "the bay's health remains dangerously out of balance." Yet despite some setbacks, the Chesapeake Bay Program shows what can be done when diverse groups work together to achieve goals that benefit both wildlife and people.

THINKING ABOUT
The Chesapeake Bay

What are three ways in which Chesapeake Bay area residents could apply the four **scientific principles of sustainability** (see back cover) to try to improve the environmental quality of the bay?

8-4 Why Are Freshwater Ecosystems Important?

▶ **CONCEPT 8-4 Freshwater ecosystems provide major ecological and economic services and are irreplaceable reservoirs of biodiversity.**

Water Stands in Some Freshwater Systems and Flows in Others

Freshwater life zones include *standing* (lentic) bodies of freshwater, such as lakes, ponds, and inland wetlands, and *flowing* (lotic) systems, such as streams and rivers. Although these freshwater systems cover less than 2.2% of the earth's surface, they provide a number of important ecological and economic services (Figure 8-14).

Lakes are large natural bodies of standing freshwater formed when precipitation, runoff, or groundwater seepage fills depressions in the earth's surface. Causes of such depressions include glaciations (Lake Louise, Alberta, Canada), crustal displacement (Lake Nyasa in East Africa), and volcanic activity (Crater Lake in the U.S. state of Oregon). Lakes are supplied with water from rainfall, melting snow, and streams that drain their surrounding watershed.

Freshwater lakes vary tremendously in size, depth, and nutrient content. Deep lakes normally consist of four distinct zones that are defined by their depth and distance from shore (Figure 8-15). The top layer, called the *littoral* ("LIT-tore-el") *zone,* is near the shore and consists of the shallow sunlit waters to the depth at which rooted plants stop growing. It has a high biological diversity because of ample sunlight and inputs of nutrients from the surrounding land. Species living in the littoral zone include many rooted plants and animals such as turtles, frogs, crayfish, and many fishes such bass, perch, and carp.

Next is the *limnetic* ("lim-NET-ic") *zone:* the open, sunlit surface layer away from the shore that extends to the depth penetrated by sunlight. The main photosynthetic body of the lake, this zone produces the food and oxygen that support most of the lake's consumers. Its most abundant organisms are microscopic phytoplankton and zooplankton. Some large fishes spend most of their time in this zone, with occasional visits to the littoral zone to feed and reproduce.

Next comes the *profundal* ("pro-FUN-dahl") *zone:* the deep, open water where it is too dark for photosynthesis to occur. Without sunlight and plants, oxygen levels are often low here. Fishes adapted to the lake's cooler and darker water are found in this zone.

The bottom of the lake contains the *benthic* ("BEN-thic") *zone,* inhabited mostly by decomposers, detritus feeders, and some fishes. The benthic zone is nourished mainly by dead matter that falls from the littoral and limnetic zones and by sediment washing into the lake.

Some Lakes Have More Nutrients Than Others

Ecologists classify lakes according to their nutrient content and primary productivity. Lakes that have a small supply of plant nutrients are called **oligotrophic** (poorly nourished) **lakes** (Figure 8-16, left). Often, this type of lake is deep and has steep banks.

Glaciers and mountain streams supply water to many such lakes, bringing little in the way of sediment or microscopic life to cloud the water. These lakes usually have crystal-clear water and small populations of phytoplankton and fishes such as smallmouth bass and trout. Because of their low levels of nutrients, these lakes have a low net primary productivity.

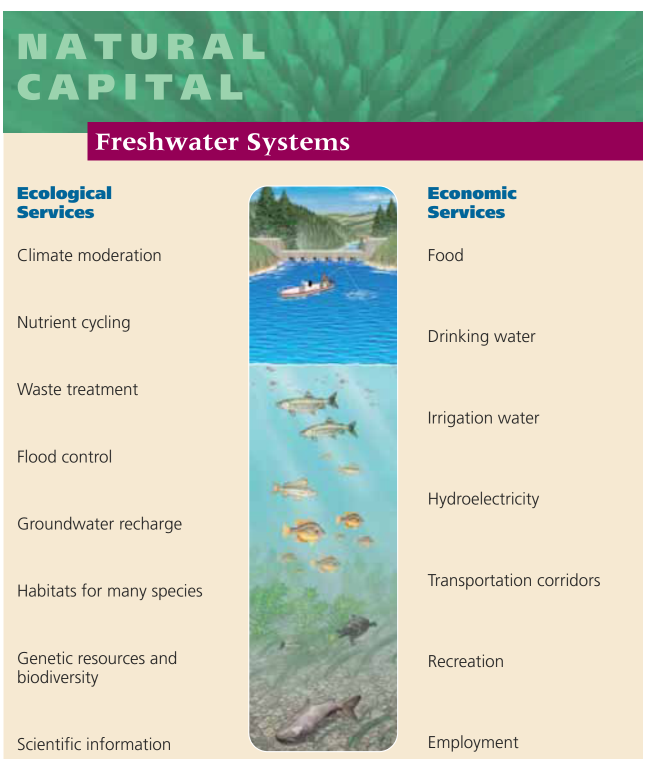
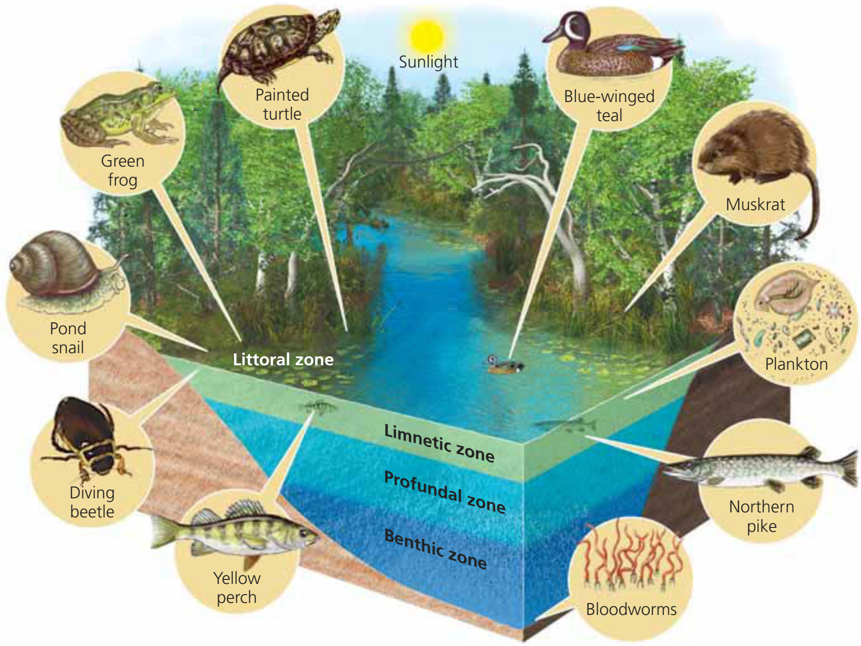


Figure 8-14 Major ecological and economic services provided by freshwater systems (**Concept 8-4**). **Question:** Which two ecological services and which two economic services do you think are the most important? Why?



CENGAGENOW™ **Active Figure 8-15** Distinct zones of life in a fairly deep temperate zone lake. *See an animation based on this figure at* CengageNOW. **Question:** How are deep lakes like tropical rain forests? (*Hint:* See Figure 7-17, p. 156)

Over time, sediment, organic material, and inorganic nutrients wash into most oligotrophic lakes, and plants grow and decompose to form bottom sediments. A lake with a large supply of nutrients needed by producers is called a **eutrophic** (well-nourished) **lake** (Figure 8-16, right). Such lakes typically are shallow and have murky brown or green water with high turbidity. Because of their high levels of nutrients, these lakes have a high net primary productivity.

Human inputs of nutrients from the atmosphere and from nearby urban and agricultural areas can accelerate the eutrophication of lakes, a process called **cultural eutrophication.** This process often puts excessive nutrients into lakes, which are then described

Jack Carey

Bill Banazewski/Visuals Unlimited

Figure 8-16 The effect of nutrient enrichment on a lake. Crater Lake in the U.S. state of Oregon (left) is an example of an *oligotrophic lake* that is low in nutrients. Because of the low density of plankton, its water is quite clear. The lake on the right, found in western New York State, is a *eutrophic lake.* Because of an excess of plant nutrients, its surface is covered with mats of algae and cyanobacteria.

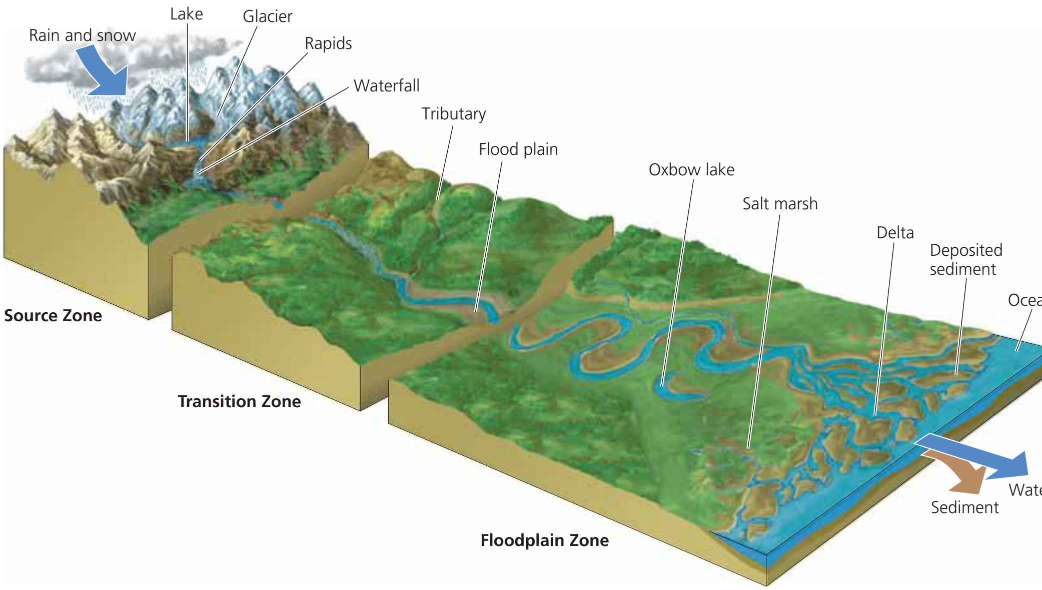


Figure 8-17 Three zones in the downhill flow of water: *source zone* containing mountain (headwater) streams; *transition zone* containing wider, lower-elevation streams; and *floodplain zone* containing rivers, which empty into the ocean.

as **hypereutrophic.** Many lakes fall somewhere between the two extremes of nutrient enrichment. They are called **mesotrophic lakes.**

Freshwater Streams and Rivers Carry Water from the Mountains to the Oceans

Precipitation that does not sink into the ground or evaporate becomes **surface water.** It becomes **runoff** when it flows into streams. A **watershed,** or **drainage basin,** is the land area that delivers runoff, sediment, and dissolved substances to a stream. Small streams join to form rivers, and rivers flow downhill to the ocean (Figure 8-17).

In many areas, streams begin in mountainous or hilly areas that collect and release water falling to the earth's surface as rain or snow that melts during warm seasons. The downward flow of surface water and groundwater from mountain highlands to the sea typically takes place in three aquatic life zones characterized by different environmental conditions: the *source zone,* the *transition zone,* and the *floodplain zone.* Rivers and streams can differ somewhat from this generalized model.

In the first, narrow *source zone* (Figure 8-17, top), headwaters, or mountain highland streams are usually shallow, cold, clear, and swiftly flowing. As this turbulent water flows and tumbles downward over waterfalls and rapids, it dissolves large amounts of oxygen from the air. Most of these streams are not very productive because of a lack of nutrients and primary producers. Their nutrients come primarily from organic matter (mostly leaves, branches, and the bodies of living and dead insects) that falls into the stream from nearby land.

The source zone is populated by cold-water fishes (such as trout in some areas), which need lots of dissolved oxygen. Many fishes and other animals in fast-flowing headwater streams have compact and flattened bodies that allow them to live under stones. Others have streamlined and muscular bodies that allow them to swim in the rapid and strong currents. Most plants are algae and mosses attached to rocks and other surfaces under water.

In the *transition zone* (Figure 8-17, middle), headwater streams merge to form wider, deeper, and warmer streams that flow down gentler slopes with fewer obstacles. They can be more turbid (from suspended sediment), slower flowing, and have less dissolved oxygen than headwater streams have. The warmer water and other conditions in this zone support more producers and cool-water and warm-water fish species (such as black bass) with slightly lower oxygen requirements.

As streams flow downhill, they shape the land through which they pass. Over millions of years, the friction of moving water may level mountains and cut deep canyons, and rock and soil removed by the water are deposited as sediment in low-lying areas. In these *floodplain zones* (Figure 8-17, bottom), streams join into wider and deeper rivers that flow across broad, flat valleys. Water in this zone usually has higher temperatures and less dissolved oxygen than water in the two higher zones. These slow-moving rivers sometimes support fairly large populations of producers such as algae and cyanobacteria and rooted aquatic plants along the shores.

Because of increased erosion and runoff over a larger area, water in this zone often is muddy and contains high concentrations of suspended particulate matter (silt). The main channels of these slow-moving, wide, and murky rivers support distinctive varieties of fishes (such as carp and catfish), whereas their backwaters support species similar to those present in lakes. At its mouth, a river may divide into many channels as it flows through deltas, built up by deposited sediment, and coastal wetlands and estuaries, where the river water mixes with ocean water (Figure 8-6).

Coastal deltas and wetlands and inland wetlands and floodplains are important parts of the earth's natural capital. They absorb and slow the velocity of floodwaters from coastal storms, hurricanes (see Case Study below), and tsunamis. Deposits of sediments and nutrients at the mouths of rivers build up protective coastal deltas.

Streams receive many of their nutrients from bordering land ecosystems. Such nutrient inputs come from falling leaves, animal feces, insects, and other forms of biomass washed into streams during heavy rainstorms or by melting snow. Thus, the levels and types of nutrients in a stream depend on what is happening in the stream's watershed.

■ CASE STUDY

Dams, Deltas, Wetlands, Hurricanes, and New Orleans

Coastal deltas, mangrove forests, and coastal wetlands provide considerable natural protection against flood damage from coastal storms, hurricanes, typhoons, and tsunamis.

When we remove or degrade these natural speed bumps and sponges, any damage from a natural disaster such as a hurricane or typhoon is intensified. As a result, flooding in places like New Orleans, Louisiana (USA), the U.S. Gulf Coast, and Venice, Italy, are largely self-inflicted unnatural disasters. For example, the U.S. state of Louisiana, which contains about 40% of all coastal wetlands in the lower 48 states, has lost more than a fifth of such wetlands since 1950 to oil and gas wells and other forms of coastal development.

Dams and levees have been built along most of the world's rivers to control water flows and provide electricity (from hydroelectric power plants). This helps to reduce flooding along rivers, but it also traps sediments that normally are deposited in deltas, which are continually rebuilt by such sediments. As a result, most of the world's river deltas are sinking rather than rising, and their protective coastal wetlands are being flooded. Thus, they no longer provide natural flood protection for coastal communities.

For example, the Mississippi River once delivered huge amounts of sediments to its delta each year. But the multiple dams, levees, and canals in this river system funnel much of this load through the wetlands and out into the Gulf of Mexico. Instead of building up delta lands, this causes them to subside. Other human processes that are increasing such subsidence include extraction of groundwater and oil and natural gas. As freshwater wetlands are lost, saltwater from the Gulf has intruded and killed many plants that depended on river water, further degrading this coastal aquatic system.

This helps to explain why the U.S. city of New Orleans, Louisiana, which was flooded by Hurricane Katrina in 2005 (Figure 8-18), is 3 meters (10 feet)

NOAA

Figure 8-18 Much of the U.S. city of New Orleans, Louisiana, was flooded by the storm surge that accompanied Hurricane Katrina, which made landfall just east of the city on August 29, 2005. When the surging water rushed through the Mississippi River Gulf Outlet, a dredged waterway on the edge of the city, it breached a floodwall, and parts of New Orleans were flooded with 2 meters (6.5 feet) of water within a few minutes. Within a day, floodwaters reached a depth of 6 meters (nearly 20 feet) in some places; 80% of the city was under water at one point. The hurricane killed more than 1,800 people, and caused more than $100 billion in damages, making it the costliest and deadliest hurricane in the U.S. history. In addition, a variety of toxic chemicals from flooded industrial and hazardous waste sites, as well as oil and gasoline from more than 350,000 ruined cars and other vehicles, were released into the stagnant floodwaters. After the water receded, parts of New Orleans were covered with a thick oily sludge.

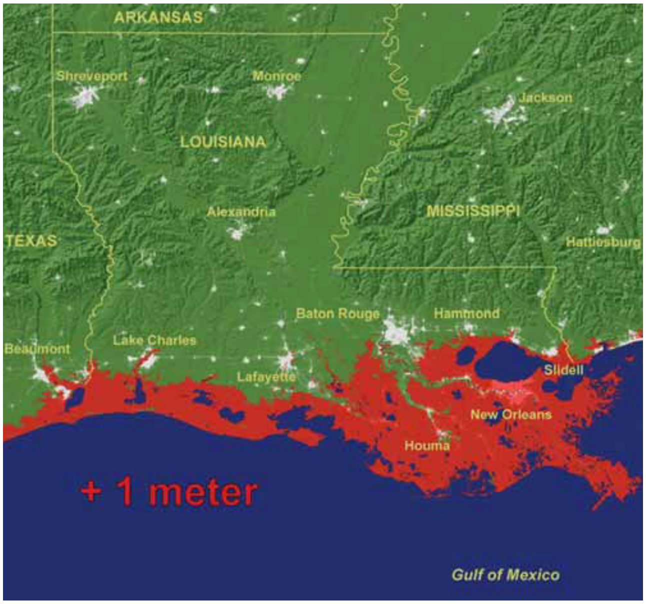


Figure 8-19 Projection of how a 1-meter (3.3-foot) rise in sea level from global warming by the end of this century would put New Orleans and much of Louisiana's current coast under water. (Used by permission from Jonathan Overpeck and Jeremy Weiss, University of Arizona)

below sea level and, in the not-too-distant future, will probably be 6 meters (20 feet) below sea level. Add to this the reduction of the protective effects of coastal and inland wetlands and barrier islands and you have a recipe for a major *unnatural* disaster.

To make matters worse, global sea levels have risen almost 0.3 meters (1 foot) since 1900 and are projected to rise 0.3–0.9 meter (1–3 feet) by the end of this century. Figure 8-19 shows a projection of how such a rise in sea level would put New Orleans and other current areas of the Louisiana coast under water. Most of this projected rise is due to the expansion of water and melting ice caused by global warming—another unnatural disaster helped along mostly by our burning of fossil fuels and clearing of large areas of the world's tropical forests.

Governments can spend hundreds of billions of dollars building or rebuilding higher levees around cities such as New Orleans. But sooner or later increasingly stronger hurricanes and rising sea levels will overwhelm these defenses and cause even greater damage and loss of life.

For example, much of New Orleans is a 3-meter (10-foot)-deep bathtub or bowl, with parts of the city 0.9–3 meters (3–9 feet) below sea level. According to engineers, even if we build levees high enough to make it a 6-meter (20-foot)-deep bathtub, a Category 5 hurricane and rising sea levels will eventually overwhelm such defenses and lead to a much more serious unnatural disaster.

The good news is that we now understand some of the connections between dams, deltas, wetlands, barrier islands, sea level rise, and hurricanes. The question is whether we will use such ecological and geological wisdom to change our ways or suffer the increasingly severe consequences of our own actions.

THINKING ABOUT
New Orleans

Do you think that a sinking city such as New Orleans, Louisiana (USA), should be rebuilt and protected with higher levees, or should the lower parts of the city be allowed to revert to wetlands that would help to protect nearby coastal areas? Explain.

Freshwater Inland Wetlands Are Vital Sponges

Inland wetlands are lands covered with freshwater all or part of the time (excluding lakes, reservoirs, and streams) and located away from coastal areas. They include *marshes* (dominated by grasses and reeds with few trees), *swamps* (dominated by trees and shrubs), and *prairie potholes* (depressions carved out by ancient glaciers). Other examples are *floodplains,* which receive excess water during heavy rains and floods, and the wet *arctic tundra* in summer (Figure 7-12, bottom photo, p. 151). Some wetlands are huge; others are small.

Some wetlands are covered with water year-round. Others, called *seasonal wetlands,* remain under water or are soggy for only a short time each year. The latter include prairie potholes, floodplain wetlands, and bottomland hardwood swamps. Some stay dry for years before water covers them again. In such cases, scientists must use the composition of the soil or the presence of certain plants (such as cattails, bulrushes, or red maples) to determine that a particular area is a wetland. Wetland plants are highly productive because of an abundance of nutrients. Many of these wetlands are important habitats for game fishes, muskrats, otters, beavers, migratory waterfowl, and many other bird species.

Inland wetlands provide a number of other free ecological and economic services, which include:

- Filtering and degrading toxic wastes and pollutants
- Reducing flooding and erosion by absorbing storm water and releasing it slowly and by absorbing overflows from streams and lakes
- Helping to replenish stream flows during dry periods
- Helping to recharge groundwater aquifers
- Helping to maintain biodiversity by providing habitats for a variety of species

- Supplying valuable products such as fishes and shellfish, blueberries, cranberries, wild rice, and timber
- Providing recreation for birdwatchers, nature photographers, boaters, anglers, and waterfowl hunters

THINKING ABOUT
Inland Wetlands

Which two ecological and economic services provided by inland wetlands do you believe are the most important? Why? List two ways in which your lifestyle directly or indirectly degrades inland wetlands.

8-5 How Have Human Activities Affected Freshwater Ecosystems?

▶ **CONCEPT 8-5 Human activities threaten biodiversity and disrupt ecological and economic services provided by freshwater lakes, rivers, and wetlands.**

Human Activities Are Disrupting and Degrading Freshwater Systems

Human activities are disrupting and degrading many of the ecological and economic services provided by freshwater rivers, lakes, and wetlands (**Concept 8-5**). Such activities affect freshwater systems in four major ways. *First,* dams, and canals fragment about 40% of the world's 237 large rivers. They alter and destroy terrestrial and aquatic wildlife habitats along rivers and in coastal deltas and estuaries by reducing water flow and increasing damage from coastal storms (Case Study, p. 177). *Second,* flood control levees and dikes built along rivers disconnect the rivers from their floodplains, destroy aquatic habitats, and alter or reduce the functions of nearby wetlands.

For example, the 2,341-mile Missouri River in the west central United States has been harnessed by levees and a series of six dams, which have disrupted the seasonal variations in the flow of the river and changed water temperatures on some stretches. This hinders the growth of insect populations and interferes with spawning cycles of fishes and the feeding habits of shorebirds, and thus severely disrupts entire food webs. The dams and levees also have interrupted sediment flow and distribution, degrading shoreline habitats maintained by sediments. As a result of these disturbances, dozens of native species have declined, and the biodiversity of the ecosystem is threatened.

A *third* major human impact on freshwater systems comes from cities and farms, which add pollutants and excess plant nutrients to nearby streams, rivers, and lakes. For example, runoff of nutrients into a lake (cultural eutrophication, Figure 8-16, right) causes explosions in the populations of algae and cyanobacteria, which deplete the lake's dissolved oxygen. When these organisms die and sink to the lake bottom, decomposers go to work and further deplete the oxygen in deeper waters. Fishes and other species can then die off, causing a major loss in biodiversity.

Fourth, many inland wetlands have been drained or filled to grow crops or have been covered with concrete, asphalt, and buildings. See the following Case Study.

■ CASE STUDY
Inland Wetland Losses in the United States

About 95% of the wetlands in the United States contain freshwater and are found inland. The remaining 5% are saltwater or coastal wetlands. Alaska has more of the nation's inland wetlands than the other 49 states put together.

More than half of the inland wetlands estimated to have existed in the continental United States during the 1600s no longer exist. About 80% of lost wetlands were destroyed to grow crops. The rest were lost to mining, forestry, oil and gas extraction, highways, and urban development. The heavily farmed U.S. state of Iowa has lost about 99% of its original inland wetlands.

This loss of natural capital has been an important factor in increased flood and drought damage in the United States—more examples of unnatural disasters. Many other countries have suffered similar losses. For example, 80% of all wetlands in Germany and France have been destroyed.

RESEARCH FRONTIER

Learning more about harmful human impacts on freshwater aquatic biodiversity and how to reduce these impacts. See **academic.cengage.com/biology/miller**.

We look further into human impacts on aquatic systems in Chapter 11. There, we also explore possible solutions to environmental problems that result from these impacts, as well as ways to sustain aquatic biodiversity.

REVISITING Coral Reefs and Sustainability

This chapter's opening case study pointed out the ecological and economic importance of the world's incredibly diverse coral reefs. They are living examples of the four **scientific principles of sustainability** in action. They thrive on solar energy, participate in the cycling of carbon and other chemicals, are a prime example of aquatic biodiversity, and have a network of interactions among species that helps to maintain sustainable population sizes.

In this chapter, we have seen that coral reefs and other aquatic systems are being severely stressed by a variety of human activities. Research shows when such harmful human activities are reduced, coral reefs and other stressed aquatic systems can recover fairly quickly.

In other words, from a scientific standpoint, we know what to do. Whether or not we act is primarily a political and ethical problem. This requires educating leaders and citizens about the ecological and economic importance of the earth's aquatic ecosystems and about the need to include the economic values of such ecosystem services in the prices of goods and services generated with the use of these resources. Solving these problems also requires individual citizens to put pressure on elected officials and business leaders to change the ways we treat these important repositories of natural capital.

. . . the sea, once it casts its spell, holds one in its net of wonders forever.

JACQUES-YVES COUSTEAU

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 163. What is a **coral reef** and why should we care about coral reefs? What is coral bleaching?

2. What percentage of the earth's surface is covered with water? What is an **aquatic life zone?** Distinguish between a **saltwater (marine)** life zone and a **freshwater** life zone. What major types of organisms live in the top, middle, and bottom layers of aquatic life zones? Define **plankton** and describe three types of plankton. Distinguish among **nekton, benthos,** and **decomposers** and give an example of each. What five factors determine the types and numbers of organisms found in the three layers of aquatic life zones? What is **turbidity,** and how does it occur? Describe one of its harmful impacts.

3. What major ecological and economic services are provided by marine systems? What are the three major life zones in an ocean? Distinguish between the **coastal zone** and the **open sea.** Distinguish between an **estuary** and a **coastal wetland** and explain why they have high net primary productivities. What is a **mangrove forest** and what is its ecological and economic importance? What is the **intertidal zone?** Distinguish between rocky and sandy shores. Why does the open sea have a low net primary productivity?

4. What human activities pose major threats to marine systems and to coral reefs?

5. Explain why the Chesapeake Bay is an estuary in trouble. What is being done about some of its problems?

6. What major ecological and economic services do freshwater systems provide? What is a **lake?** What four zones are found in most lakes? Distinguish among **oligotrophic, eutrophic, hypereutrophic,** and **mesotrophic lakes.** What is **cultural eutrophication?**

7. Define **surface water, runoff,** and **watershed (drainage basin).** Describe the three zones that a stream passes through as it flows from mountains to the sea. Describe the relationships between dams, deltas, wetlands, hurricanes, and flooding in New Orleans, Louisiana (USA).

8. Give three examples of **inland wetlands** and explain the ecological importance of such wetlands.

9. What are four ways in which human activities are disrupting and degrading freshwater systems? Describe inland wetlands in the United States in terms of the area of wetlands lost and the resulting loss of ecological and economic services.

10. How is the degradation of many of the earth's coral reefs (**Core Case Study**) a reflection of our failure to follow the four **scientific principles of sustainability**? Describe this connection for each principle.

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. List three ways in which you could apply **Concepts 8-3** and **8-5** to make your lifestyle more environmentally sustainable.

2. What are three steps governments and industries could take to protect remaining coral reefs (**Core Case Study**)? What are three ways in which individuals can help to protect those reefs? CORE CASE STUDY

3. Why do aquatic plants such as phytoplankton tend to be very small, whereas most terrestrial plants such as trees tend to be larger and have more specialized structures such as stems and leaves for growth?

4. Why are some aquatic animals, especially marine mammals such as whales, extremely large compared with terrestrial animals?

5. How would you respond to someone who proposes that we use the deep portions of the world's oceans to deposit our radioactive and other hazardous wastes because the deep oceans are vast and are located far away from human habitats? Give reasons for your response.

6. Suppose a developer builds a housing complex overlooking a coastal salt marsh and the result is pollution and degradation of the marsh. Describe the effects of such a development on the wildlife in the marsh, assuming at least one species is eliminated as a result. (See Figure 8-7.)

7. How does a levee built on a river affect species such as deer and hawks living in a forest overlooking the river?

8. Suppose you have a friend who owns property that includes a freshwater wetland, and the friend tells you he is planning to fill the wetland to make more room for his lawn and garden. What would you say to this friend?

9. Congratulations! You are in charge of the world. What are the three most important features of your plan to help sustain the earth's aquatic biodiversity?

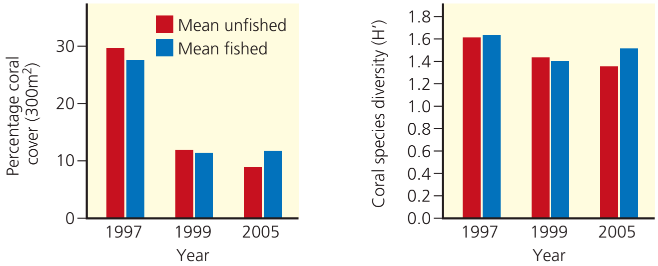
10. List two questions that you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

DATA ANALYSIS

At least 25% of the world's coral reefs have been severely damaged. A number of factors have played a role in this serious loss of aquatic biodiversity (Figure 8-12, right, p. 172), including ocean warming, sediment from coastal soil erosion, excessive algae growth from fertilizer runoff, coral bleaching, rising sea levels, overfishing, and damage from hurricanes.

In 2005, scientists Nadia Bood, Melanie McField, and Rich Aronson conducted research to evaluate the recovery of coral reefs in Belize from the combined effects of mass bleaching and Hurricane Mitch in 1998. Some of these reefs are in protected waters where no fishing is allowed. The researchers speculated that reefs in waters where no fishing is allowed should recover faster than reefs in water where fishing is allowed. The graphs below show some of the data they collected from three highly protected (no fishing) sites and three unprotected (fishing) sites to evaluate their hypothesis.



Effects of restricting fishing on the recovery of unfished and fished coral reefs damaged by the combined effects of mass bleaching and Hurricane Mitch in 1998. (Data from Melanie McField, et al., *Status of Caribbean Coral Reefs After Bleaching and Hurricanes in 2005*, NOAA, 2008. (Report available at **www.coris.noaa.gov/activities/caribbean_rpt/**)

1. By about what percentage did the mean coral cover drop in the protected (unfished) reefs between 1997 and 1999?
2. By about what percentage did the mean coral cover drop in the protected (unfished) reefs between 1997 and 2005?
3. By about what percentage did the coral cover drop in the unprotected (fished) reefs between 1997 and 1999?
4. By about what percentage did the coral cover change in the unprotected (fished) reefs between 1997 and 2005?
5. Do these data support the hypothesis that coral reef recovery should occur faster in areas where fishing is prohibited? Explain.

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 8 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.