CHAPTER 11

Sustaining Aquatic Biodiversity and Ecosystem Services

With every drop of water you drink, with every breath you take, you are connected to the sea, no matter where on Earth you live.

SYLVIA EARLE

Key Questions

11.1 What are the major threats to aquatic biodiversity and ecosystem services?

11.2 How can we protect and sustain marine biodiversity?

11.3 How should we manage and sustain marine fisheries?

11.4 How should we protect and sustain wetlands?

11.5 How should we protect and sustain freshwater lakes, rivers, and fisheries?

11.6 What should be our priorities for sustaining aquatic biodiversity?

Endangered green sea turtle swimming over a coral reef.

George Grall/National Geographic Creative

Core Case Study

The Great Jellyfish Invasion

Jellyfish, which are not fish, were the first invertebrate animals in the earth's oceans. They dominated the oceans for at least 500 million years in the Precambrian period, long before fish evolved (see Supplement 6, p. S46).

A jellyfish (see Figure 8.2, p. 169) is mostly made of water and has no brain, blood, head, heart, bones, or protective shell. The bell-shaped bodies of jellyfish are filled with a jelly-like substance. A network of nerves at the base of their dangling tentacles can detect warmth, food, odors, and vibration.

Jellyfish move by drifting on water currents and by squirting pulsating jets of water from their bodies. They use tentacles dangling from their bodies to sting or stun prey, to draw food into their mouth on the underside of their body, and to defend themselves against predators such as other jellyfish, tuna, sharks, swordfish, and sea turtles.

Jellyfish eat almost anything that floats their way. Most are carnivorous and typically feed on zooplankton, fish eggs, small fish, shrimp, and other jellyfish. They are caught for food in 15 countries, and are considered a delicacy in countries such as China and Japan.

Jellyfish sizes vary widely. Some are as small as a mosquito. The largest jellyfish is the lion's mane (Figure 11.1). It has a body up to 2.4 meters (8 feet) wide, has tentacles as long as 30 meters (100 feet), and can weigh as much as 150 kilograms (350 pounds).

The sting of a jellyfish can cause itching or a burning sensation that lasts for several days. Most stings occur when people accidentally brush up against a jellyfish. However, a sting from the Portuguese man-of-war, the Australian box jelly, or the tiny Irukandji jellyfish can kill a human within minutes if untreated. Each year, the stings of lethal jellyfish kill around 40 people on average.

Jellyfish are often found in large swarms or *blooms* of thousands, even millions of individuals. In recent years, the numbers of these blooms observed by scientists and fishers have been rising. Often they are as long as five to six city blocks, and one *megabloom* was about 300 meters (1,000 feet) long.

These blooms have a number of harmful economic effects. They cause beach closings, disrupt commercial fishing operations by clogging or tearing holes in nets, wipe out coastal fish farms, and clog ship engines. They can also close down coal-burning and nuclear power plants by blocking their cooling water intakes.

According to Chinese oceanographer Wei Hao and other marine scientists, the startling growth of jellyfish populations threatens to upset marine food webs and ecosystem services and turn some of the world's most productive ocean areas into jellyfish empires. Once jellyfish take over a marine ecosystem, they might dominate it for millions of years, as they did in the Precambrian period. Later in this chapter, we discuss why jellyfish populations have been increasing at an alarming rate.

In this chapter, we examine the effects of human activities on aquatic biodiversity. We also explore ways to prevent or lessen these effects in order to help sustain aquatic life.

wizdata/Fotolia LLC

FIGURE 11.1 The lion's mane is the largest jellyfish species. It can grow to 30 meters (100 feet) in length.

11.1 WHAT ARE THE MAJOR THREATS TO AQUATIC BIODIVERSITY AND ECOSYSTEM SERVICES?

CONCEPT 11.1 Aquatic species and the ecosystem and economic services they provide are threatened by habitat loss, invasive species, pollution, climate change, and overexploitation—all made worse by the growth of the human population and resource use.

We Have Much to Learn about Aquatic Biodiversity

We live on a water planet with 71% of its surface covered by salty ocean water to an average depth of 3.7 kilometers (2.3 miles). Yet, we have explored less than 5% of the earth's interconnected oceans and know relatively little about marine biodiversity and its many functions. We also have limited knowledge about freshwater biodiversity.

Scientists have observed three general patterns related to marine biodiversity. *First*, the greatest marine biodiversity occurs around coral reefs, in estuaries, and on the deep-ocean floor. *Second*, biodiversity is greater near the coasts than in the open sea because of the larger variety of producers and habitats in coastal areas. *Third*, biodiversity is generally greater in the bottom region of the ocean than in the surface region because of the larger variety of habitats and food sources on the ocean bottom.

The deepest part of ocean, where sunlight does not penetrate (see Figure 8.5, p. 171), is the planet's least explored environment but this is changing. More than 2,400 scientists from 80 countries are working on a 10-year project to catalog the species in the deep ocean zone. They have used remotely operated deep-sea vehicles to identify more than 17,000 species living in this zone and are adding a few thousand new species every year.

Why should we care about sustaining life in the oceans? What difference will it make if coral reefs, sharks, or whales disappear? There are a number of economic, health-related, and ecological reasons:

- Worldwide, about 850 million jobs in fishing and tourism depend on the oceans.
- About 40% of the world's people get 15–20% of their animal protein and essential nutrition from seafood.
- Oceans generate more than half of the oxygen we breathe.
- Oceans help slow atmospheric warming and climate change by absorbing about 25% of the carbon dioxide produced by human activities.
- Oceans absorb 90% of the excess heat we add to the atmosphere.
- Natural barriers such as coral reefs, mangrove forests, and sea-grass beds reduce the impacts from tsunamis and major storms.

These economic and ecosystem services are provided by the diversity of species living and interacting in the oceans. This explains why learning about and sustaining marine biodiversity should be one of our top priorities. Freshwater systems, which occupy only 1% of the earth's surface, also provide important economic and ecological services (see Figure 8.14, p. 179).

Human Activities Are Destroying and Degrading Aquatic Habitats

Human activities have destroyed or degraded much of the world's coastal wetlands, coral reefs, mangroves, and ocean bottom. They also have disrupted many freshwater ecosystems. In a 2015 study, ecologist Douglas J. McCauley and a team of other scientists reviewed data about the state of the oceans from hundreds of sources and concluded that "the oceans are facing a major extinction event." They also said that "the impacts are accelerating but they're not so bad we can't reverse them."

As with terrestrial biodiversity, the greatest threats to aquatic biodiversity and ecosystem services can be remembered with the aid of the acronym HIPPCO, with H standing for *habitat loss and degradation* (**Concept 11.1**). Scientists reported in 2006 that coastal habitats were disappearing at rates 2 to 10 times higher than the rate of tropical forest loss.

Shallow, warm-water coral reefs are centers of aquatic biological diversity (Figure 11.2 and Chapter 8, Core Case Study, p. 168). These crown jewels of the ocean occupy only 0.1% of the world's oceans, but are home for about 25% of world's marine fish species.

Since the 1950s, about half of the world's shallow, warm-water coral reefs (90% in the Indian Ocean and Caribbean) have been destroyed (Figure 11.3) or degraded, and another 25–33% could be lost within 20 to 40 years, according to the Global Coral Reef Monitoring Network. Threats include coastal development, overfishing, pollution, warmer ocean water, and ocean acidification (Science Focus 11.1).

Today, shallow coral reefs, on average, are exposed to the warmest and most acidic ocean waters of the past 400,000 years—a double threat from the excess carbon dioxide that we have been adding to the atmosphere, mostly from burning fossil fuels. Warmer ocean waters can cause shallow tropical corals to expel their colorful algae and leave behind white coral—a process called **coral bleaching** (see Figure 8.1, p. 168). It can weaken and sometimes kill corals. Marine biologist Malin L. Pinsky said: "If you cranked up the aquarium heater and dumped some acid in the water, your fish would not be very happy. In effect, that's what we are doing to the oceans."

Vlad61/Shutterstock.com

FIGURE 11.2 Coral reefs are endangered centers of aquatic biodiversity.

Richard Whitcombe/Shutterstock.com

FIGURE 11.3 Dead coral reef.

CONSIDER THIS . . .

CONNECTIONS Sunscreens and Coral Reefs

Certain ingredients in many sunscreens have been shown to promote the growth of a harmful virus within the algae that live in coral reefs. When people dive down to see the reefs, these chemicals can wash off. This can kill the algae and promote coral bleaching.

If given enough time, many species of corals can adapt to changes in environmental conditions such as warmer and perhaps more acidic water. However, corals are threatened with rapidly rising water temperatures, acidity, and sea levels during this century, which will not give them enough time for adaptation.

According to fossil and other evidence, coral reefs were devastated in each of the earth's five mass extinctions that took place over the last half-billion years (see Figure 4.19, p. 93). Evidence indicates that, in each mass extinction, high levels of dissolved CO_2 and prolonged ocean warming and acidification played a role in dissolving the calcium carbonate that coral polyps use to build the reefs. With each mass extinction, the corals disappeared and did not come back for 4 million to 10 million years. If we have triggered a sixth mass extinction as some scientists say, many of the coral species that are currently centers of marine biodiversity are likely to disappear again for millions of years.

CONSIDER THIS . . .

LEARNING FROM NATURE

Some reefs have been resilient enough to recover from coral bleaching, and scientists are researching how this occurs. Scientists are also investigating how shallow reefs in certain naturally acidic waters have survived.

United Nations Environment Programme (UNEP) scientists reported that a fifth of the world's ecologically and economically important mangrove forests (see Figure 8.8 p. 172) have been lost since 1980. They continue to be destroyed for firewood, coastal construction, and shrimp farming. Another study revealed that 58% of the world's coastal sea-grass beds (see Figure 8.9, p. 173) have been degraded or destroyed, mostly by dredging and coastal development.

Sea-bottom habitats are faring no better. Each year, like giant submerged bulldozers, thousands of trawler fishing boats drag up to 60-meter-wide (200-foot-wide) nets weighted down with chains and steel plates over the ocean floor to harvest a few species of bottom fish and shellfish (Figure 11.4). This destroys large areas of deep, cold-water coral reefs and other ocean-bottom habitats, which could take decades or centuries to recover. According to marine scientist Elliot Norse, "Bottom trawling is probably the largest human-caused disturbance to the biosphere." An increase in seabed mining also threatens biologically diverse ocean-bottom habitats.

Habitat disruption is also a problem in freshwater aquatic zones. The main causes are the building of dams and excessive withdrawal of river water for irrigation and urban water supplies. These activities destroy aquatic habitats, decrease water flows, and disrupt freshwater biodiversity. Globally, the extinction rate for freshwater species is 5 times the rate for terrestrial species, according to the latest IUCN Red List.

Ocean acidification (Science Focus 11.1) could kill off much of the oceans' phytoplankton that are the base of marine food webs. According to a study by marine scientist Ove Hoegh-Guldberg and 16 other scientists, unless we take action soon to significantly reduce CO_2 emissions, the oceans may become too acidic and too warm for most of the world's coral reefs to survive this century.

Invasive Species Can Degrade Aquatic Biodiversity

Another threat to aquatic biodiversity is the deliberate or accidental introduction of hundreds of harmful

SCIENCEFOCUS 11.1

Ocean Acidification: The Other CO_2 Problem

By burning increasingly large amounts of carbon-containing fossil fuels, especially since 1950, we have added carbon dioxide (CO_2) to the atmosphere faster than it can be removed by the carbon cycle (see Figure 3.20, p. 65)

Extensive research indicates that this increase in the atmospheric concentration of CO_2 has played a key role in the observed increase in the atmosphere's average temperature, especially since 1980, and has changed the earth's climate. Research and climate models indicate that continuing to increase CO_2 levels in the atmosphere will likely lead to severe disruption of the earth's climate during this century, as we discuss in Chapter 19.

Another serious environmental problem related to CO_2 emissions is *ocean acidification*, a change in ocean chemistry. The oceans have helped reduce atmospheric warming and climate change by absorbing about 25% of the excess CO_2 that human activities have added to the atmosphere. When this absorbed CO_2 combines with ocean water, it forms carbonic acid (H_2CO_3), a weak acid also found in carbonated drinks. This increases the level of hydrogen ions (H^+) in the water and makes the water less basic (with a lower pH; see Figure 2.6, p. 36). This also decreases the level of carbonate ions (CO_3^{2-}) in the water because these ions react with hydrogen ions (H^+) to form bicarbonate ions (HCO_3^-).

The problem is that many aquatic species—including phytoplankton, corals, sea snails, crabs, and oysters—use carbonate ions to produce calcium carbonate ($CaCO_3$), the main component of their shells and bones. In less basic waters, carbonate ion concentrations drop (Figure 11.A) and shell-building species and coral reefs grow more slowly. When the hydrogen ion concentration of seawater gets high enough, their calcium carbonate begins to dissolve. Species that survive will have damaged or weaker shells and bones.

According to a 2013 study by more than 540 of the world's leading experts on ocean acidification, the average acidity of ocean water has risen 30% (actually a 30% decrease in average basicity) since 1800. It has risen 15% since the 1990s, with the largest increase occurring in deep cold waters near the poles, especially in the Arctic Sea, and along the West Coast of the United States and is projected to keep acidifying throughout this century. According to the report, the oceans are acidifying "faster than at any time during the last 300 million years."

Evidence indicates that this change in ocean chemistry is contributing to coral bleaching, to holes in the shells of tiny sea snails in the U.S. Pacific Ocean, and to die-offs at oyster farms off the coast of Washington and Oregon. More research is needed to evaluate the ecological impacts of a warmer and more acidic ocean and to determine whether some of the affected organisms can adapt to such changes.

Because the world's oceans are a key component of our life-support system, a survival rule should be *do not change the chemistry of the oceans*—a rule that we are violating. According to the world's key ocean acidification scientific experts, we are altering the chemistry of the entire ocean ecosystem from the tropics to the poles with little idea of the consequences.

Ocean acidification is a serious threat to ocean life, terrestrial life, and the human species and economies. If we fail to act rapidly to reduce this serious threat, marine biologists project that ocean food webs will shift dramatically, as corals and other calcifying organisms die off and as green algae and jellyfish, which thrive in acidic and warm waters, become more dominant (**Core Case Study**).

CRITICAL THINKING

How might widespread losses of some forms of marine aquatic life due to ocean acidification affect life on land? How might it affect your life? (*Hint:* Think food webs.)

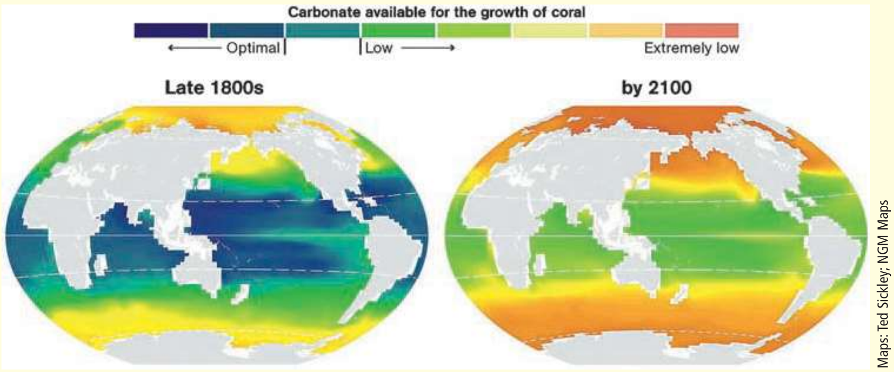
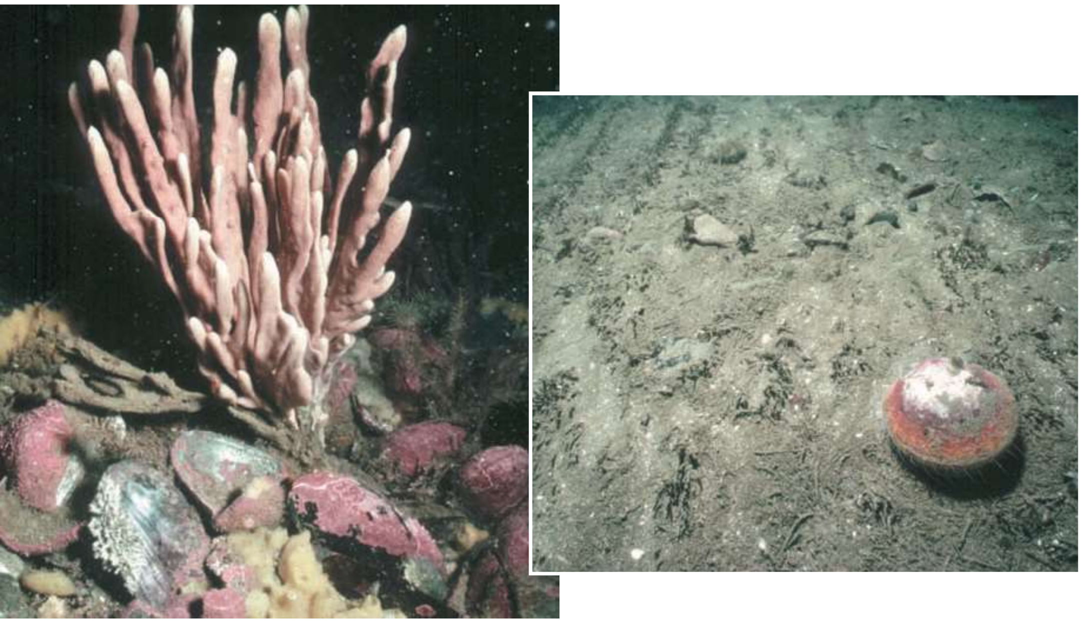


FIGURE 11.A Calcium carbonate levels in ocean waters, calculated from historical data (left), and projected for 2100 (right). Colors shifting from blue to red indicate where waters are becoming less basic. In the late 1800s, when CO_2 began to pile up rapidly in the atmosphere, tropical corals were not yet affected by ocean acidification. However, today carbonate levels have dropped substantially near the Poles, and by 2100, they may be too low even in the tropics for most coral reefs to survive. (Sources: Andrew G. Dickson, Scripps Institution of Oceanography, U.C. San Diego, and Sarah Cooley, Woods Hole Oceanographic Institution. Used by permission from National Geographic.)



Courtesy of Peter J. Auster/National Undersea Research Center

FIGURE 11.4 Natural capital degradation: An area of ocean bottom before (left) and after (right) a trawler net scraped it like a gigantic bulldozer. ***Critical thinking:*** What land activities are comparable to this?

invasive species (see Figure 9.9, p. 201)—the I in HIPPCO—into coastal waters, wetlands, and lakes throughout the world (**Concept 11.1**). According to the U.S. Fish and Wildlife Service, bioinvaders are blamed for about two-thirds of all fish extinctions in the United States since 1900 and have caused huge economic losses.

Many of the more than 1,450 different aquatic invader species in the United States arrived in the ballast water stored in tanks in large cargo ships to keep them stable. The ships take in ballast water from one harbor, along with whatever microorganisms and tiny fish species it contains, and dump it into another—an environmentally and economically harmful effect of globalized trade. Even when ballast water is flushed from an oceangoing ship's tank before it enters a harbor—which is now required in many ports—the ship can still bring invaders that are stuck to its hull.

One invader that worries scientists and the fishing industry on the east coast of North America is a species of *lionfish*, native to the western Pacific Ocean (Figure 11.5). Scientists believe it escaped from outdoor aquariums in Miami, Florida, that were damaged by Hurricane Andrew in 1992.

Lionfish populations have exploded at the highest rate of any species ever recorded by scientists in this part of the world. One scientist described the lionfish as "an almost perfectly designed invasive species." It reaches sexual maturity rapidly, has large numbers of offspring, and is protected by venomous spines. It competes with popular reef fish species such as grouper and snapper, taking their food and eating their young. One ray of hope for controlling this population is that the lionfish tastes good. Scientists are hoping to see a growing market for lionfish as seafood, but it is difficult and costly to prepare.

CONSIDER THIS . . .

CONNECTIONS Lionfish and Coral Reef Destruction

Researchers have found that lionfish eat at least 50 species of prey fish, including parrotfish, that normally consume enough algae around coral reefs to keep the algae from overgrowing and killing the corals. Scientists warn that, where lionfish are now the dominant species such as in the Bahamas, unchecked algae could overwhelm and destroy some coral reefs.

In addition to threatening native species, invasive species can disrupt and degrade whole ecosystems and their ecosystem services. This is the focus of study for a growing number of researchers (Science Focus 11.2).

Population Growth and Pollution Can Reduce Aquatic Biodiversity

According to UNEP, about 80% of the world's people live along or near seacoasts, mostly in large coastal cities. This coastal population growth—the first P in HIPPCO—has added to the already intense pressure on the world's coastal zones (**Concept 11.1**).

The oceans have become a sewer for much of the chemical, biological, and solid wastes that humans produce. The UNEP estimates that about 80% of all ocean pollution—the second P in HIPPCO—comes from land-based coastal activities.

Today, more than 400 oxygen-depleted zones ("dead zones") have formed in coastal areas around the world, and the number is increasing. They form when high levels of plant nutrients from fertilizers and soil erosion flow from the land into rivers that empty into coastal waters. These inputs support large algal blooms. When these algae die, they sink to the bottom, where bacteria begin to decompose them. Because the decomposition requires

SCIENCEFOCUS 11.2

How Invasive Carp Have Muddied Some Waters

Lake Wingra lies within the city of Madison, Wisconsin, surrounded mostly by a forest preserve. The lake contains a number of invasive plant and fish species, including purple loosestrife (see Figure 9.9, p. 201) and common carp. The carp were introduced in the late 1800s and since then have made up as much as half of the fish biomass in the lake. They devour algae called *chara*, which would normally cover the lake bottom and stabilize its sediments. Consequently, fish movements and winds stir these sediments, which accounts for much of the water's excessive *turbidity*, or cloudiness.

Knowing this, Dr. Richard Lathrup, a limnologist (lake scientist) who worked with Wisconsin's Department of Natural Resources, hypothesized that removing the carp would help to restore the natural ecosystem of Lake Wingra. Lathrop speculated that if the carp were removed, the bottom sediments would settle and become stabilized, allowing the water to clear. Clearer water would in turn allow native plants to receive more sunlight and become reestablished on the lake bottom, replacing purple loosestrife and other invasive plants that now dominate its shallow shoreline waters.

Lathrop and his colleagues installed a thick, heavy vinyl curtain around a 1-hectare (2.5-acre), square-shaped perimeter that extended out from the shore. This barrier hung from buoys on the surface to the bottom of the lake, isolating the volume of water within it. The researchers then removed all of the carp from this study area and began observing results. Within 1 month, the waters within the barrier were noticeably clearer, and within a year, the difference in clarity was dramatic (Figure 11.B) and native plants once again grew in the shallow shoreline waters.

Lathrop notes that removing and keeping carp out of Lake Wingra would be a daunting task, perhaps impossible, but his controlled scientific experiment clearly shows the effects that an invasive species can have on an aquatic ecosystem. And it reminds us that preventing the introduction of invasive species in the first place is the best and least expensive way to avoid such effects.

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FIGURE 11.B *Lake Wingra* in Madison, Wisconsin (USA) became clouded with sediment partly because of the introduction of invasive species such as the common carp. Removal of carp in the experimental area shown here resulted in a dramatic improvement in the clarity of the water.

CRITICAL THINKING

What are two other results of this controlled experiment that you might expect? (*Hint:* Think food webs.)

oxygen, levels of this dissolved gas in the water become depleted. Marine organisms either suffocate due to lack of dissolved oxygen or leave the area if they can. It is another example of how human activities can lead to changes in ocean chemistry and biodiversity.

Toxic pollutants from industrial and urban areas can kill some forms of aquatic life by poisoning them. Some highly toxic mercury in ocean waters comes from natural sources. However, toxic mercury released into the atmosphere by coal-burning plants can be taken up by ocean producers and magnified to high levels in ocean food webs. Because of this input from natural and human sources, top predator fish such as sharks, tilefish, swordfish, king mackerel, and white tuna can contain high levels of toxic mercury.

Cigdem Cooper/Shutterstock.com

FIGURE 11.5 The *common lionfish* has invaded the eastern coastal waters of North America, where it has few, if any, predators.

FIGURE 11.6 This Hawaiian monk seal was slowly starving to death before a discarded piece of plastic was removed from its snout.

Partially decomposed particles of plastic items dumped from ships and garbage barges, and left as litter on beaches, kill up to 1 million seabirds and 100,000 mammals annually (Figure 11.6). These animals mistake the plastic particles for plankton or small fish. Certain compounds in these plastics can be concentrated in some types of seafood that people eat.

Climate Change Is a Growing Threat

Climate change—the C in HIPPCO—threatens aquatic biodiversity (**Concept 11.1**) and ecosystem services. Greenhouse gas emissions and heat, mostly from the burning of fossil fuels, have played an important role in warming the atmosphere and changing the earth's climate. For decades, the earth's oceans have absorbed about 90% of this excess heat. If they had not, the earth's atmosphere would be much warmer and the climate would be changing much more rapidly. As energy expert John Abraham puts it: "The ocean is doing us a favor by grabbing about 90% of our heat output. But it is not going to do it forever."

As a result, the ocean has been getting warmer. The surface warms the most, but vertical currents (see Figure 7.11, p. 147) transfer some of this heat to deep water. This ocean heating affects marine food webs and makes some marine habitats unlivable for some species by exceeding the range of temperatures they can tolerate (see Figure 5.15, p. 110). Unless they can migrate to cooler water, they can face extinction. Measurements indicate that the ability of the ocean to absorb heat is slowing. Eventually some of this heat will flow back into the atmosphere and accelerate atmospheric warming and climate change.

Ocean warming has caused some marine species to migrate from the equator toward the poles to cooler waters. This can threaten some of these species because their new habitats can be less hospitable, having lower dissolved oxygen levels. A warmer ocean could also boost populations of some species such as the coral-eating thorn-of-crown starfish that poses a threat to Australia's Great Barrier Reef.

The ocean has removed and dissolved about 27% of the excess CO_2 we have added to the atmosphere. Because of ocean currents, most of this CO_2 ends up in the southern hemisphere oceans and is forced into deep ocean waters by whirlpools driven by winds. As the ocean warms, it holds less CO_2. The combination of rising ocean temperatures could release huge amounts of CO_2 into the atmosphere and trigger rapid climate change.

A big threat from a warmer ocean is a rising sea level due to thermal expansion as ocean water warms and the partial melting of land-based ice in glaciers and ice sheets as atmospheric temperatures rise. In 2014 the Intergovernmental Panel on Climate Change (IPCC) estimated that the average global sea level is likely to rise by 40–60 centimeters (1.3–2 feet) by the end of this century—about 10 times the rise that occurred in the 20th century. Recent research projects a rise of 1.1–1.2 meters (3–4 feet) by 2100.

Such a rise in sea level would destroy shallow coral reefs, swamp some low-lying islands, drown many coastal wetlands, and put many coastal areas such as a large part of the U.S. Gulf and East Coasts underwater (see Figure 8.21, p. 186). In addition, some Pacific island nations could lose more than half of their protective coastal mangrove forests by 2100, according to a UNEP study.

CONSIDER THIS . . .

CONNECTIONS Protecting Mangroves and Dealing with Climate Change

Protecting mangrove forests and restoring them in areas where they have been destroyed are important ways to reduce the impacts of rising sea levels and storm surges, because mangroves forests can slow storm-driven waves. These ecosystem services will become more important if tropical storms become more intense because of climate change. Protecting and restoring these natural coastal barriers is much cheaper and more effective than building concrete sea walls or moving threatened coastal towns and cities inland.

Warmer and more acidic ocean water is also stressing phytoplankton, the foundation of marine food webs (see Figure 3.16, p. 60). These tiny life forms produce half of the earth's oxygen and absorb a great deal of the CO_2 emitted by human activities. A team of scientists led by marine ecologist Boris Worm found that global phytoplankton populations have declined by 40% since the 1950s, probably because of warmer and more acidic ocean waters.

Overfishing and Overharvesting: Gone Fishing, Fish Gone

Fish and fish products provide 20% of the world's animal protein for billions of people. A **fishery** is a concentration of a wild aquatic species suitable for commercial harvesting in a given ocean area or inland body of water.

Today, 4.4 million fishing boats hunt for and harvest fish from the world's oceans. These industrial fishing fleets use global satellite positioning equipment, sonar fish-finding devices, huge nets, long fishing lines, spotter planes and drones, and refrigerated factory ships that can process and freeze their enormous catches. These highly efficient fleets supply the growing demand for seafood, but critics say that they are overfishing many species (Figure 11.7), reducing marine biodiversity, and degrading important marine ecosystem services. Figure 11.8 shows the major methods used for the commercial harvesting of various marine fishes and shellfish.

For example, trawlers have destroyed vast areas of ocean-bottom habitat (Figure 11.4). In addition, their nets often capture endangered sea turtles (Figure 11.9), causing them to drown.

Another fishing method, *purse-seine fishing* (Figure 11.8), is used to catch surface-dwelling species such as tuna, mackerel, anchovies, and herring, which tend to feed in schools near the surface or in shallow waters. After a spotter plane locates a school, the fishing vessel encloses it with a large purse-seine net. Some of these nets have killed large numbers of dolphins that swim on the surface above schools of tuna.

Some fishing vessels also use *long-lining*, which involves putting out lines up to 100 kilometers (60 miles) long, hung with thousands of baited hooks to catch swordfish, tuna, sharks, and ocean-bottom species such as halibut and cod. Long lines also hook and kill large numbers of sea turtles, dolphins, and seabirds each year.

With *drift-net fishing*, fish are caught by drifting nets that can hang as deep as 15 meters (50 feet) below the surface and extend to 64 kilometers (40 miles) long. These nets trap and kill large quantities of unwanted fish, called **bycatch,** along with marine mammals and sea turtles. Nearly one-third of the world's annual fish catch by weight consists of bycatch species that are mostly thrown overboard dead or dying. This adds to the depletion of these species and puts stress on some of the species that feed on them.

A **fishprint** is the area of ocean needed to sustain the fish consumption of an average person, a nation, or the world based on the weight of fish they consume annually. It helps scientists and government officials distinguish between sustainable and unsustainable levels of fishing and evaluate the effects of policy change. The world's fishing nations are harvesting more fish than their populations can sustain in the long run. According to the Woods Hole Oceanographic Institute, 57% of the world's commercial fisheries have been fully exploited and another 30% have been overfished.

87% Percentage of the world's commercial fisheries that have been fully exploited or overfished

In most cases, overfishing leads to *commercial extinction*, which occurs when it is no longer profitable to continue harvesting the affected species. Overfishing can temporarily deplete a species, as long as depleted areas and fisheries are allowed to recover. However, as industrialized fishing fleets take more and more of the world's available fish and shellfish, recovery times for severely depleted populations are increasing and can be two decades or more. Some depleted fisheries may not recover as jellyfish and other invasive species move in and take over their food webs (**Core Case Study**).

In the late 1950s, fishing fleets began overfishing the 500-year-old northwest Atlantic cod fishery off the coast of Newfoundland, Canada. They used bottom trawlers to

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MARK EDWARDS/Still Pictures/Aurora Photos

FIGURE 11.7 The threatened Atlantic bluefin tuna is being overfished because of its high market value.

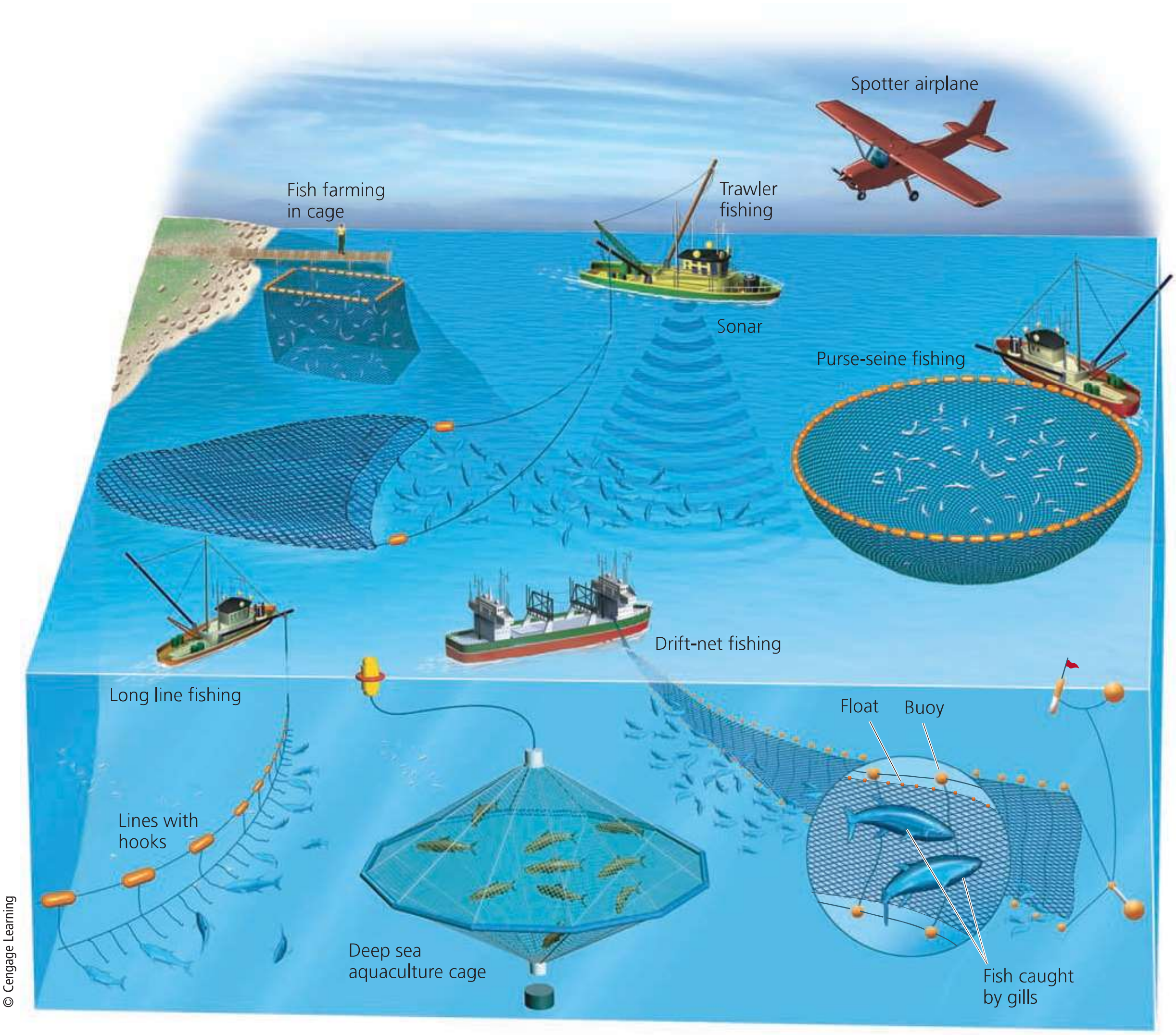

FIGURE 11.8 Major commercial fishing methods used to harvest various marine species, along with some methods used to raise fish through aquaculture.

capture larger shares of the stock, reflected in the sharp rise in the graph in Figure 11.10. This extreme overexploitation of the fishery led to a steady decline in the fish catch throughout the 1970s. After a slight recovery in the 1980s, the fishery collapsed and in 1992 it was shut down. This put at least 35,000 fishers and fish processors out of work in more than 500 coastal communities. The fishery was reopened on a limited basis in 1998, but in 2003 it was closed indefinitely.

One result of the increasingly efficient global hunt for fish is that larger individuals of commercially valuable wild species—including cod, marlin, swordfish, and tuna—are becoming scarce. A study conducted by scientists at Dalhousie University in Canada found that 90% or more of these and other large, predatory, open-ocean fishes disappeared between 1950 and 2006, a trend that is increasing. Another effect of overfishing is that when larger predatory species dwindle, rapidly reproducing invasive species such as jellyfish (**Core Case Study**) can take over and disrupt ocean food webs.

As commercially valuable species are overfished, the fishing industry has turned to other species such as sharks, which are now being overfished (see the Case Study that follows). In addition, as large species are overfished, the fishing industry has been working its way down to lower trophic levels of marine food webs by shifting to smaller marine species such as anchovies, herring, sardines, and shrimp-like krill—known as forage fish. Ninety percent of

FIGURE 11.9 This endangered green sea turtle died after being caught in a fishing net.

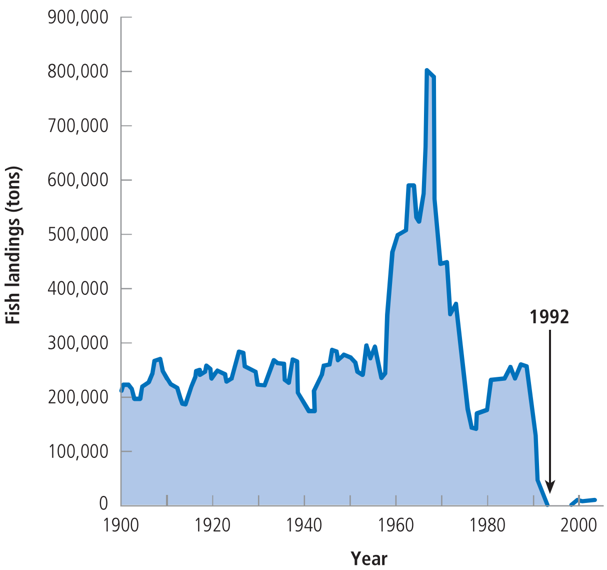

FIGURE 11.10 Natural capital degradation: Collapse of Newfoundland's Atlantic cod fishery. ***Data analysis:*** By roughly what percentage did the catch of Atlantic cod drop between the peak catch in 1960 and 1970? (Compiled by the authors using data from Millennium Ecosystem Assessment.)

this catch is converted to fishmeal and fish oil, and fed to farmed fish. Scientists warn that this reduces the food supply for larger fish species and makes it harder for them to rebound from overfishing. The result will be further disruption of marine ecosystems and their ecosystem services. Overfishing can also make affected species more vulnerable to the stresses of ocean warming and ocean acidification. Marine mammals such as whales are also threatened by overfishing (see the second Case Study that follows).

Industrialized fishing—humanity's last large-scale hunting and gathering operation—requires huge amounts of energy to propel the ships, fuel spotter planes, and freeze the catches. According to a 2014 study by Robert Parker, the species that require the largest energy input are, in order, shrimp, lobster, Pacific albacore tuna, scallops, and skipjack tuna.

CASE STUDY

Why Should We Protect Sharks?

Sharks have roamed the world's oceans for at least 400 million years. Certain shark species are keystone species in their ecosystems. Sharks, like any good predator feeding at or near the tops of their food webs, probably remove injured and sick animals. Without this ecosystem service, the oceans would teem with dead and dying fish

 

FIGURE 11.11 The threatened whale shark (left), which feeds on plankton, is the ocean's largest fish and is quite friendly to humans. The scalloped hammerhead shark (right) is endangered.

Left: Colin Parker/National Geographic My Shot/National Geographic Creative Right: Frantisek hojdysz/Fotolia LLC

and marine mammals. Shark activity also influences the distribution and feeding habits of other species, which helps maintain balance in marine ecosystems.

The world's more than 480 known species of sharks vary widely in size. They range from the 15-centimeter (6-inch) long dwarf dog shark to the whale shark (Figure 11.11, left), which can grow to the length of a city bus and weigh as much as two full-grown African elephants.

Many people, influenced by movies, popular novels, and media coverage of shark attacks, think of sharks as vicious monsters. In reality, the three largest species—the whale shark (Figure 11.12, left), basking shark, and megamouth shark—are gentle giants. These sharks swim through the water with their mouths open, filtering out and swallowing huge quantities of zooplankton and small fish.

Media reports on shark attacks greatly exaggerate the dangers to humans from sharks. Every year, members of a few species, including the great white, bull, tiger, and hammerhead sharks (Figure 11.11, right), injure 60 to 80 people, and typically kill 6 to 10 people worldwide. Sometimes these sharks are thought to mistake swimmers and people on surfboards or paddle boards for their usual prey of sea lions and other marine mammals. According to shark attack files at the Florida Museum of History, you are much more likely to be killed by a falling coconut or by falling out of bed than by a shark. In 2014 more people in the world were killed taking selfies (12) than by shark attacks (8).

Each year human activities kill more than 200 million sharks. As many as 73 million sharks die each year after being caught for their valuable fins, a practice called *shark finning*. After capture, their fins are cut off. Then the sharks are thrown into the water and in the worst cases, they bleed to death or drown because they can no longer swim. Sharks are also killed for their livers, meat, hides, and jaws, and because we fear or hate them. Each year, an estimated 100 million sharks die when fishing lines and nets trap them.

Harvested shark fins are widely used in Asia as an ingredient in expensive soup ($100 or more a bowl) and as an alleged pharmaceutical cure-all. The large dorsal fin of a whale shark (Figure 11.11, left) can be worth up to $10,000 in Hong Kong or Taiwan and is often hung outside Asian restaurants to advertise shark fin soup. According to the wildlife conservation group WildAid, there is no reliable evidence that shark fins provide flavor or have any nutritional or medicinal value. The group also warns that consuming shark fins and shark meat can be harmful to human health because they contain high levels of mercury and other toxins.

According to a 2014 IUCN study, 25% of the world's open-ocean shark species are threatened with extinction, primarily from overfishing. Because some sharks are keystone species, their extinction can threaten the ecosystems and the ecosystem services they provide. Sharks are especially vulnerable to population declines because they grow slowly, mature late, and have only a few offspring per generation. Today, sharks are among the earth's most vulnerable and least protected animals.

With research support from the National Geographic Society, biologist Samuel H. Gruber has been studying lemon sharks in the Florida Keys and the Bahamas. One of his goals is to help us understand and reduce the slaughter of these sharks, which he calls "fantastic and amazing creatures." Protecting sharks is one way for us to live more sustainably by increasing our beneficial environmental impacts.

CONSIDER THIS . . .

LEARNING FROM NATURE

Sharks easily glide through the water because tiny grooves in their skin form continuous channels for water flow. Scientists are studying this to design ship hulls that will save energy and money by moving through the water with less resistance.

CASE STUDY

Protecting Whales: A Success Story . . . So Far

Overharvesting threatens some marine mammals with extinction. The most prominent examples are whales, or *cetaceans*, that range in size from the 0.9-meter (3-foot) porpoise to the giant 15- to 30-meter (50- to 100-foot) highly endangered blue whale. Cetaceans are divided into two major groups: *toothed whales* and *baleen whales* (Figure 11.12).

Toothed whales, such as the porpoise, sperm whale, and killer whale (orca), bite and chew their food and feed mostly on squid, octopus, and other marine animals. *Baleen whales*, such as the blue, gray, humpback, minke, and fin, are filter feeders. Attached to their upper jaws are plates made of baleen, or whalebone, which they use to filter plankton, especially tiny shrimp-like krill (Figure 3.16, p. 60), from the seawater.

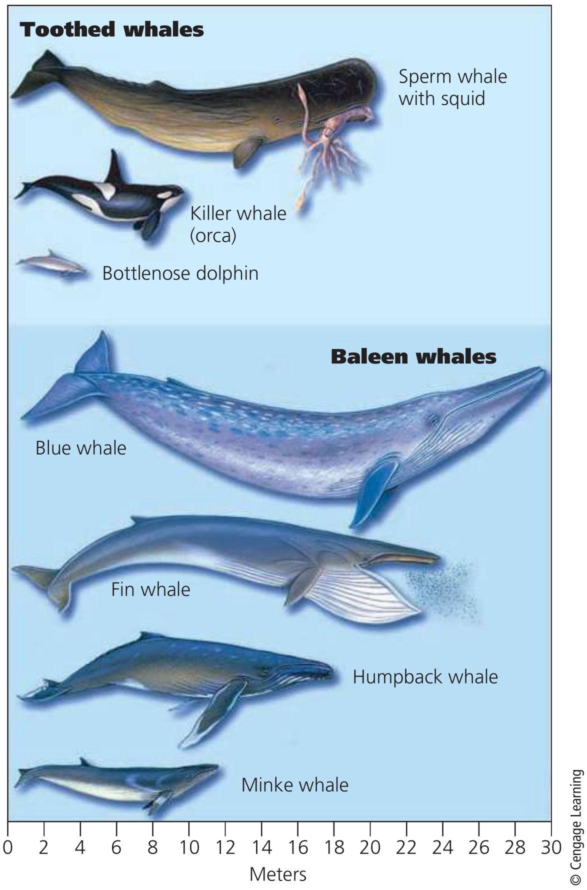

FIGURE 11.12 Cetaceans are classified as either toothed whales or baleen whales.

Whales are easy to kill because of their large size and because of their need to come to the surface to breathe. Whale hunters became efficient at hunting and killing whales using radar, spotters in airplanes, fast ships, and harpoon guns. Whale harvesting, mostly in international waters, has followed the classic pattern of a tragedy of the commons (p. 12). In the 20th century, about 3 million whales were killed by whalers from 46 countries, led by Norway, Japan, the U.S.S.R., and the United Kingdom. Between 1925 and 1975, this overharvesting drove 8 of the 11 major species to commercial extinction and the blue whale close to biological extinction.

The endangered blue whale is the earth's largest animal. Its heart is the size of a small car, its tongue weighs as much as an adult elephant, and some of its blood vessels are big enough for you to swim through. Also, it is one of the fastest-swimming animals in the sea.

In 1946 the International Whaling Commission (IWC) was established to regulate the whaling industry by setting annual quotas to prevent overharvesting. However, IWC quotas often were based on insufficient data or were ignored by whaling countries. Without enforcement powers, the IWC was not able to stop the decline of most commercially hunted whale species.

In 1970 the United States stopped all commercial whaling and banned all imports of whale products. Under pressure from conservationists and governments of many nonwhaling nations, the IWC imposed a moratorium on commercial whaling starting in 1986. It worked. The estimated number of whales killed commercially worldwide dropped from 42,480 in 1970 to about 2,000 in 2014.

Most whaling today is done by Japan, Norway, and Iceland. Since the 1986 ban on commercial whaling, these nations and some tropical island nations have pressured the IWC to lift the ban and reverse the international ban on buying and selling whale products. They contend that the ban on whaling is emotionally motivated and interferes with their cultural diet traditions, which they say are no different from the western cultural tradition of killing cows for beef. Many conservationists dispute this claim and contend that whales are intelligent and highly social mammals that should be protected for ethical and ecological reasons.

Whaling proponents also point out that populations of minke, humpback, and several other whale species have rebounded enough since the moratorium on whaling to be removed from the ban. Others question IWC estimates of the allegedly recovered whale species, noting the inaccuracy of such estimates in the past.

Extinction of Aquatic Species Is a Growing Threat

Beyond the *commercial extinction* of a number of fish species, many marine and freshwater fish species are threatened with *biological extinction* mostly because of a combination of habitat loss, overfishing, pollution, and ocean acidification.

Among the most threatened of all marine species are sea turtles (see chapter-opening photo) that have been roaming the oceans for more than 110 million years—about 550 times longer than our species has been around. Today six of the seven species of sea turtles (Figure 11.13) are in danger of becoming extinct, mostly because human activities taking place during the last 100 years have reduced the world's number of sea turtles by about 95%.

Sea turtles spend most of their lives traveling throughout the world's oceans, but adult females normally return to the beaches where they were born to lay their eggs. They come ashore at night and use their back flippers to dig nests on sand beaches and coastal dunes. Each female lays a clutch of around 100 to 110 eggs, buries them, and returns to the ocean. After the baby turtles hatch, they dig their way out of the nest, often at night, to scamper toward the water. During this dangerous trip, birds and other predators eat many of them. Only about one of every thousand sea turtle hatchlings survives to adulthood.

Sea turtles are threatened by trawler fishing (Figure 11.4), which destroys many of the coral gardens that have served as their feeding grounds. The turtles are also hunted for their skin and their eggs are taken for food. They often drown after becoming entangled in fishing nets (Figure 11.9) and lines, as well as in lobster and crab traps.

Beachgoers and motor vehicles sometimes crush their nests. Artificial lights can disorient newly hatched baby turtles, which try to find their way to the ocean by moving toward moonlight reflected from the ocean's surface. Going in the wrong direction increases their chances of ending up as food for predators.

Pollution of ocean water is another threat. Sea turtles can mistake discarded plastic bags for jellyfish and choke to death trying to eat them. In addition, the threat of rising sea levels from climate change during this century will flood many sea turtle nesting habitats and change ocean currents, which could disrupt their migration routes.

Several sea turtle species eat jellyfish (**Core Case Study**) and help control their populations. Continuing population declines of these endangered sea turtles could promote the takeover of parts of the sea by rapidly expanding populations of jellyfish (Science Focus 11.3).

In U.S. waters, the National Marine Fisheries Service requires the use of turtle excluder devices on commercial fishing nets that allow captured sea turtles to escape (Figure 11.14). Since 1990, fishing regulations have reduced accidental sea turtle deaths in U.S. waters by 90%. GOOD NEWS

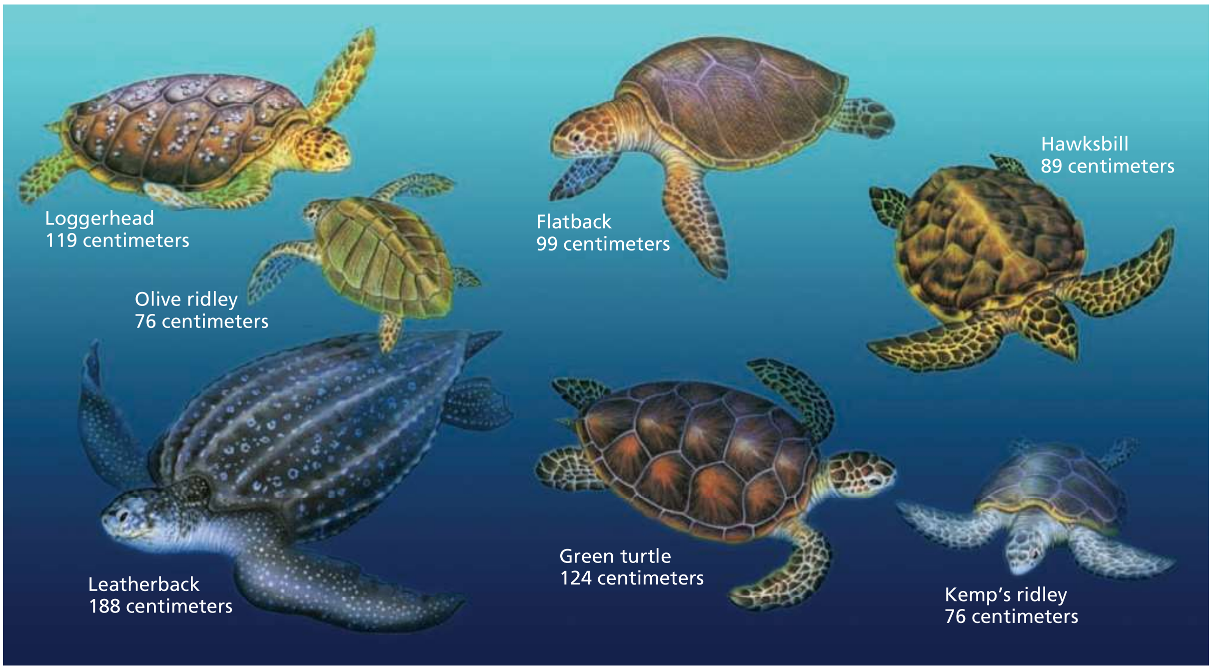

FIGURE 11.13 There are seven species of sea turtles, six of them threatened with extinction. All but the flatback are found in U.S. waters.

SCIENCEFOCUS 11.3

Why Are Jellyfish Populations Increasing?

Jellyfish look fragile but have a number of survival traits. They can reproduce rapidly, survive without food for long periods of time by shrinking and waiting until conditions improve, eat many different things, and feed in murky waters. They can also survive in low-oxygen, warm, and acidic waters.

Scientists have identified several possible causes for the increased number and size of jellyfish swarms in many areas of the world's oceans (**Core Case Study**). One likely factor is the decline in populations of their natural predators such as tuna, sharks, swordfish, and endangered sea turtles, mostly due to overfishing. Overfishing also increases food sources for jellyfish because it reduces populations of fish such anchovies and sardines that eat much of the same food as jellyfish. As humans overfish commercially valuable fish species, jellyfish can take over, eat fish eggs and small fish, and hinder or prevent the recovery of overfished species.

Human activities play a key role in ocean warming and ocean acidification, which are favorable for jellyfish. Another environmental change caused by human activities is the overfertilization of coastal waters by huge inputs of the plant nutrients nitrogen and phosphorus. They come from the runoff of fertilizers from large areas of land into rivers that flow into coastal waters. The excess plant nutrients create massive blooms of algae and other plankton, which die, sink, and are decomposed. This process, called *cultural eutrophication*, depletes dissolved oxygen in ocean bottom waters and kills or drives away marine organisms that require oxygen. Jellyfish populations can erupt in these so-called "dead zones" such as the massive one that forms each year in the Gulf of Mexico. At least 400 other dead zones, where almost nothing but jellyfish survive, form in various parts of the world.

Jellyfish have also benefited from the rapid increase in global trade involving ships carrying goods throughout the world. Some species of jellyfish can survive in the ballast water of ships, and polyps of various jellyfish species can attach to ship hulls and end up inhabiting new areas of the ocean throughout the world.

More research is needed, but the rise of jellyfish in the world's ocean waters is probably the result of a mixture of these factors. Think about it. We are doing things that favor jellyfish: depleting populations of their major predators, depleting populations of fish species that compete with them for food, warming and making the oceans more acidic, creating numerous large oxygen-depleted zones, and using ships to spread them throughout the world.

CRITICAL THINKING

What are two ways in which exploding jellyfish populations might affect your life or the lives of any children and grandchildren you might eventually have?

© NOAA

FIGURE 11.14 This endangered loggerhead turtle is escaping a fishing net equipped with a turtle excluder device.

11.2 HOW CAN WE PROTECT AND SUSTAIN MARINE BIODIVERSITY?

CONCEPT 11.2 We can help to sustain marine biodiversity by using laws and economic incentives to protect species, setting aside marine reserves to protect ecosystems and ecosystem services, and using community-based integrated coastal management.

We Can Protect Marine Species with Laws and Treaties

Protecting marine biodiversity is difficult for several reasons:

- The human ecological footprint and the fishprint are expanding so rapidly that it is difficult to monitor their impacts.
- Much of the damage to the oceans and other bodies of water is not visible to most people.
- Many people incorrectly view the seas as an inexhaustible resource that can absorb an almost

infinite amount of waste and pollution and still produce all the seafood we want.

- Most of the world's ocean area lies outside the legal jurisdiction of any country. Thus, much of it is an open-access resource, subject to overexploitation. This is a classic example of the tragedy of the commons (see Chapter 1, p. 12).

Nevertheless, there are several ways to protect and sustain marine biodiversity, thereby increasing our beneficial environmental impact. One involves *passing and enforcing laws* (**Concept 11.2**). For example, we can protect endangered and threatened aquatic species, as discussed in Chapter 9.

National and international laws and treaties that help protect marine species include the 1975 Convention on International Trade in Endangered Species (CITES), the 1979 Global Treaty on Migratory Species, the U.S. Marine Mammal Protection Act of 1972, the U.S. Endangered Species Act of 1973 (ESA; see pp. 211–213), the U.S. Whale Conservation and Protection Act of 1976, and the 1995 International Convention on Biological Diversity. The ESA and several international agreements have been used to identify and protect endangered and threatened marine species, including whales, seals, sea lions, and sea turtles. However, it is hard to get all nations to comply with some of these agreements. Even when agreements and regulations are enforced, the resulting fines and punishments for violators are often inadequate.

We Can Establish Marine Sanctuaries

By international law, a country's offshore fishing zone extends to 370 kilometers (200 nautical miles) from its shores. Foreign fishing vessels can take certain quotas of fish within such zones, called *exclusive economic zones*, but only with a government's permission. Ocean areas beyond the legal jurisdiction of any country are known as the *high seas*, and laws and treaties pertaining to them are difficult to monitor and enforce.

For example, illegal poachers catch an estimated one of every five fish sold in stores and served in restaurants. This illegal catch is difficult to monitor and control. However, in 2015 a new satellite tracking system, funded by the Pew Charitable Trusts, was launched to help crack down on this illegal activity.

The United Nations Law of the Sea treaty, which went into effect in 1984, has been signed by 162 countries but not by the United States. Under this treaty, the world's coastal nations have jurisdiction over 36% of the ocean surface and 90% of the world's fish stocks. Instead of using this treaty to protect their fishing grounds, many governments have promoted overfishing by subsidizing fishing fleets and failing to establish and enforce stricter regulation of fish catches in their coastal waters.

We can establish *protected marine sanctuaries*. Since 1986, the IUCN has helped several nations to establish a global system of *marine protected areas* (MPAs)—areas of ocean partially protected from human activities. According to the U.S. National Ocean Service, there are more than 5,800 MPAs worldwide. MPAs cover 2.8% of the world's ocean surface and their numbers are growing.

However, most MPAs allow dredging, trawler fishing (Figure 11.4), and other ecologically harmful resource extraction activities. Many of them are too small to be effective in protecting larger species. However, since 2007, the U.S. state of California has been establishing the nation's most extensive network of MPAs in which fishing is banned or strictly limited. In 2011 Costa Rica (see Chapter 10, Core Case Study, p. 222) expanded one of its MPAs to help protect a number of marine species, including the critically endangered leatherback sea turtle and the endangered scalloped hammerhead shark (Figure 11.11, right). The United States has nearly 1,800 MPAs, which receive varying degrees of protection.

Marine Reserves: An Ecosystem Approach to Marine Sustainability

Scientists and policy makers call for protecting and sustaining entire marine ecosystems and their ecosystem services within a global network of fully protected *marine reserves*, some of which already exist. These areas are declared off-limits to commercial fishing, dredging, mining, and waste disposal in order to enable their ecosystems to recover and flourish.

When patrolled and protected, marine reserves work and they work quickly. Studies show that in fully protected marine reserves, on average, commercially valuable fish populations double, average fish size grows by almost a third, fish reproduction triples, and species diversity increases by almost one-fourth. These improvements can happen within 2 to 4 years after strict protection begins. Reserves also benefit nearby fisheries because fish move into and out of the reserves. Currents also carry fish larvae produced inside reserves to adjacent fishing grounds, thus bolstering fish populations there. In addition, marine reserves increase the ability of protected marine ecosystems to respond to the growing stresses of ocean warming and ocean acidification. In 2014 the United States created the world's largest marine reserve by expanding its Kingman Reef Reserve around a couple of remote Pacific Islands (Figure 11.15). This marine reserve is more than twice the size of the U.S. state of Texas. Deep-sea mining and tuna fishing are banned in these waters.

Despite the importance of protected reserves, only 1.2% of the world's oceans are fully protected compared to 5% of the world's land. In addition, many of the existing reserves are fully protected only on paper because of shortages of funding and a need for more trained staff to manage and monitor them. In other words, at least 98.8%

FIGURE 11.15 Gray reef sharks in the recently expanded Kingman Reef Reserve in the Pacific Ocean.

of the world's oceans are not effectively protected from harmful human activities.

98.8%
Percentage of the world's oceans that lack effective protection from harmful human activities

Many marine scientists want to increase our beneficial environmental impact by setting aside 10–30% of the world's oceans as fully protected marine reserves. Sylvia Earle, one of the world's leading marine scientists, is spearheading this effort (Individuals Matter 11.1).

Marine scientists also call for establishing protected corridors to connect the global network of marine reserves, especially those in coastal waters. This would help species move to different habitats in response to the effects of ocean warming, acidification, and many forms of ocean pollution.

CONSIDER THIS . . .

THINKING ABOUT Marine Reserves

Do you support setting aside at least 30% of the world's oceans as fully protected marine reserves? Explain. How would this affect your life?

Restoration Helps Protect Marine Biodiversity, but Prevention Is the Key

A dramatic example of marine system restoration is Japan's attempt to restore its largest coral reef—90% of it dead—by seeding it with new corals. Divers drill holes into the dead reefs and insert ceramic discs holding sprigs of fledgling coral. Figure 11.16 shows how protection has helped to restore coral reefs near Kanton Island, an atoll located in the South Pacific.

Many scientists support efforts to restore aquatic systems, but they warn that these projects could fail if the problems that caused their degradation are not addressed. They call for more emphasis on *preventing aquatic ecosystem degradation*, which is far less expensive and more effective than restoration efforts.

For example, a study by IUCN and scientists from the Nature Conservancy concluded that the world's shallow coral reefs and mangrove forests could survive currently projected climate change if we reduce other threats such as overfishing and pollution. However, while some shallow coral species may be able to adapt to warmer temperatures, they may not have enough time to do this unless we act now to slow down the rate of ocean warming.

To deal with problems of pollution and overfishing, marine scientists call for countries and coastal communities to closely monitor and regulate fishing and coastal land development and greatly reduce pollution from land-based activities. Coastal residents should also think about

INDIVIDUALS MATTER 11.1

Sylvia Earle—Advocate for the Oceans

Tyrone Turner/National Geographic Creative

Sylvia Earle is one of the world's most respected oceanographers and is a National Geographic Explorer. She has taken a leading role in helping us to understand and protect the world's oceans. *Time* magazine named her the first Hero for the Planet and the U.S. Library of Congress calls her "a living legend."

Earle has led more than 100 ocean research expeditions and has spent more than 7,000 hours underwater, either diving or descending in research submarines to study ocean life. She has focused her research on the ecology and conservation of marine ecosystems, with an emphasis on developing deep-sea exploration technology.

She is the author of more than 175 publications and has been a participant in numerous radio and television productions. During her long career, Earle has also served as the Chief Scientist of the U.S. National Oceanic and Atmospheric Administration (NOAA). She also founded three companies that develop submarines and other devices for deep-sea exploration and research. She has received more than 100 major international and national honors, including a place in the National Women's Hall of Fame.

Earle is currently leading a campaign called Mission Blue to finance research and to ignite public support for a global network of marine protected areas, which she calls "hope spots." Her goal is to help save and restore the oceans, which she calls "the blue heart of the planet." She says, "There is still time, but not a lot, to turn things around. . . . This mostly blue planet has kept us alive. It's time for us to return the favor."

Brian J. Skerry/National Geographic Creative

FIGURE 11.16 Recovery of a coral reef in a protected area near Kanton Island in the South Pacific.

the chemicals they put on their lawns and the kinds of waste they generate, much of which ends up in coastal waters.

One strategy emerging in some coastal communities is *integrated coastal management*—a community-based effort to develop and use coastal resources more sustainably (**Concept 11.2**). The overall aim of such programs is for fishers, business owners, developers, scientists, citizens, and politicians to identify shared problems and goals in their use of marine resources. The idea is to develop workable, cost-effective, and adaptable solutions that will help to preserve biodiversity, ecosystem services, and environmental quality, while also meeting economic and social goals.

This requires participants to seek reasonable short-term trade-offs that can lead to long-term ecological and economic benefits—an example of applying the win-win **principle of sustainability**. For example, fishers might have to give up harvesting various fish species in certain areas until stocks recover enough to restore biodiversity in those areas. This might help them to secure a more sustainable future for their businesses.

Australia manages its huge Great Barrier Reef Marine Park in this way, and more than 100 integrated coastal management programs are being developed throughout the world. Another example of such management in the United States is the Chesapeake Bay Program (see Chapter 8, Case Study, p. 177).

11.3 HOW SHOULD WE MANAGE AND SUSTAIN MARINE FISHERIES?

CONCEPT 11.3 Sustaining marine fisheries will require improved monitoring of fish and shellfish populations, cooperative fisheries management among communities and nations, reduction of fishing subsidies, and careful consumer choices in buying seafood.

We Need to Estimate and Monitor Fishery Populations

The first step in protecting and sustaining the world's marine fisheries is to make the best possible estimates of their fish and shellfish populations (**Concept 11.3**). The traditional approach has used a *maximum sustained yield (MSY)* model to project the maximum number of individuals that can be harvested annually from fish or shellfish stocks without causing a population drop. However, the MSY concept has not worked very well because of the difficulty in estimating the populations and growth rates of fish and shellfish stocks. In addition, harvesting a particular species at its estimated maximum sustainable level can affect the populations of other marine species.

In recent years, some fishery biologists and managers have begun using the *optimum sustained yield (OSY)* concept, which attempts to take into account interactions among species. Similarly, another approach is *multispecies management* of a number of interacting species, which takes into account their competitive and predator–prey interactions. An even more ambitious approach is to develop complex computer models for managing multispecies fisheries in *large marine systems*. However, it is a political challenge to get groups of nations to cooperate in planning and managing such large systems.

There are uncertainties built into using any of these approaches because the biology of marine species and their interactions is poorly understood, and because of limited data on changing ocean conditions. As a result, many fishery and environmental scientists are increasingly interested in using the *precautionary principle* for managing fisheries and large marine systems. This means sharply reducing fish harvests and closing some overfished areas until they recover and until we have more information about what levels of fishing they can sustain.

Some Communities Cooperate to Regulate Fish Harvests

An obvious step to take in protecting marine biodiversity—and therefore fisheries—is to regulate fishing. Traditionally, many coastal fishing communities have developed allotment and enforcement systems for controlling fish catches in which each fisher gets a share of the total allowable catch. Such *catch-share systems* have sustained fisheries and jobs in many communities for hundreds and sometimes thousands of years.

However, the influx of large state-of-the-art fishing boats and international fishing fleets has weakened the ability of many coastal communities to regulate and sustain local fisheries. Community management systems have often been replaced by *co-management*, in which coastal communities and the government work together to manage fisheries. Currently, more than 700 of the world's fisheries are co-managed.

With this approach, a central government typically sets quotas for various species and divides the quotas among communities. The government may also limit fishing seasons and regulate the types of fishing gear that can be used to harvest a particular species. Each community then allocates and enforces its quota among its members based on its own rules. When it works, community-based co-management illustrates that we can prevent overfishing and the tragedy of the commons.

Government Subsidies Can Encourage Overfishing

Governments around the world give more than $30 billion per year in subsidies to fishers to help them keep their businesses running, according to fishery experts U. R. Sumaila and Daniel Pauly. Some marine scientists estimate that, each year, $10 billion to $14 billion of these subsidies is spent to encourage overfishing and expansion of the fishing industry. The result is too many boats chasing too few fish. Some argue that such subsidies are not a wise investment because they promote overfishing of targeted fish stocks, which causes economic losses of about $50 billion a year, according to the World Bank.

CONSIDER THIS . . .

THINKING ABOUT Fishing Subsidies

Do you think that government fishing subsidies that promote unsustainable fishing should be eliminated or drastically reduced? Explain. Would your answer be different if your livelihood depended on commercial fishing?

Consumers Can Choose Sustainably Produced Seafood

An important component of sustaining aquatic biodiversity and ecosystem services is bottom-up pressure from consumers who demand *sustainably produced seafood* (**Concept 11.3**). We can purchase only sustainably harvested seafood or sustainably farmed seafood. One way to help consumers make such choices is to label sustainably caught and raised fresh and frozen fish and shellfish. The London-based Marine Stewardship Council (MSC) was created in 1999 to support sustainable fishing and to certify sustainably produced seafood. Only certified fisheries are allowed to use the MSC's "Fish Forever" eco-label, which certifies that the fish were caught by fishers who used environmentally sound and socially responsible practices. Another approach is to certify and label products of sustainable *aquaculture*, or fish-farming operations.

An important way for consumers of seafood raised by aquaculture to help sustain aquatic biodiversity is to choose plant-eating species of fish, such as tilapia, catfish, and carp. Carnivorous species, such as salmon and shrimp, raised through aquaculture are often fed fishmeal made from wild-caught fish and some of these species are being overfished.

Individuals can also help reduce the waste of seafood. Between 2009 and 2013, about 45% of all edible seafood in the United States ended up in the trash, mostly because consumers and restaurants did not cook it before it spoiled. Figure 11.17 summarizes actions that individuals, organizations, and governments can take to help sustain global fisheries, marine biodiversity, and ecosystem services.

Solutions

Managing Fisheries

Fishery Regulations

Set low catch limits

Improve monitoring and enforcement

Economic Approaches

Reduce or eliminate fishing subsidies

Certify sustainable fisheries

Protection

Establish no-fishing areas

Establish more marine protected areas

Consumer Information

Label sustainably harvested fish

Publicize overfished and threatened species

Bycatch

Use nets that allow escape of smaller fish

Use net escape devices for seabirds and sea turtles

Aquaculture

Restrict locations of fish farms

Improve pollution control

Nonnative Invasions

Kill or filter organisms from ship ballast water

Clean aquatic recreation gear

FIGURE 11.17 Ways to manage fisheries more sustainably and protect marine biodiversity. ***Critical thinking:*** Which four of these solutions do you think are the best ones? Why?

11.4 HOW SHOULD WE PROTECT AND SUSTAIN WETLANDS?

CONCEPT 11.4 We can maintain the ecosystem and economic services of wetlands by protecting remaining wetlands and restoring degraded wetlands.

Coastal and Inland Wetlands Are Disappearing

Coastal wetlands and marshes (Figure 8.7, p. 172) and inland wetlands support aquatic biodiversity and provide vital economic and ecosystem services. Their ecosystem services include feeding downstream waters, reducing flooding by storing storm water, reducing storm damage by absorbing waves (coastal wetlands), recharging groundwater supplies, reducing pollution, preventing erosion, and providing fish and wildlife habitat.

Despite their ecological value, the United States has lost more than half of its coastal and inland wetlands since 1900. Other countries have lost even more, and the rate of loss of wetlands throughout the world is accelerating. China, for example, has lost about 60% of its original coastal wetlands, New Zealand has lost 92%, and Italy has lost 95%.

The U.S. state of Louisiana has the largest area of coastal wetlands in the lower 48 states but is losing them faster than any other state. One cause of such losses is subsidence (sinking) of coastal land near the Mississippi River delta. Because the river is heavily dammed, sediments that naturally replenish the delta do not make it to the Gulf of Mexico, so the delta is shrinking and the land subsiding. Other threats to coastal wetlands are oil spills and a rising sea level due to climate change.

For centuries, people have drained, filled in, or covered over swamps, marshes, and other wetlands to create rice fields or other cropland, to accommodate expanding cities and suburbs, and to build roads. Wetlands have also been destroyed to extract minerals, oil, and natural gas, and to eliminate breeding grounds for insects that cause diseases such as malaria. To make matters worse, coastal wetlands in many parts of the world will probably be under water before the end of this century because of rising sea levels.

Preserving and Restoring Wetlands

Some laws protect wetlands. In the United States, zoning laws have been used to steer development away from wetlands. The U.S. government requires a federal permit to fill in wetlands occupying more than 1.2 hectares (3.0 acres) or to deposit dredged material in wetlands. According to the U.S. Fish and Wildlife Service, this law has helped to cut the average annual wetland loss by 80% since 1969.

However, there are continuing attempts by land developers to weaken such wetlands protection. Only about 6% of the country's remaining inland wetlands are federally protected, and state and local wetland protection is inconsistent and generally weak because of intense pressure from coastal developers and landowners.

94% Percentage of U.S. inland wetlands that are not protected by federal law against development and degradation

The stated goal of current U.S. federal policy is *zero net loss* in the functioning and value of coastal and inland wetlands. A policy known as *mitigation banking* allows destruction of existing wetlands as long as an equal or greater area of the same type of wetland is created, enhanced, or restored. However, a study by the National Academy of Sciences found that at least half of the attempts to create new wetlands failed to replace lost ones. Furthermore, most of the created wetlands did not provide the ecosystem services of natural wetlands, even decades after completion. The study also found that wetland creation and restorations often fail to meet the standards set for them and are not adequately monitored.

Creating and restoring wetlands has become a profitable business. Private investment bankers make money by buying wetland areas and restoring or upgrading them or creating new wetland. This creates wetlands banks or credits that the bankers sell to developers. This approach is a small step toward full-cost pricing because it puts a monetary value on the biodiversity and ecosystem services of wetlands that are sold by the bankers.

However, it is difficult to restore, enhance, or create wetlands (see the Case Study that follows). Thus, most U.S. wetland banking systems require replacing each area of destroyed wetland with twice the same area of restored, enhanced, or created wetland (Figure 11.18) as a built-in ecological insurance policy.

Ecologists urge using mitigation banking only as a last resort. They also call for making sure that new replacement wetlands are created and evaluated *before* existing wetlands are destroyed. This example of applying the precautionary principle is usually the reverse of what is actually done.

CONSIDER THIS . . .

THINKING ABOUT Wetlands Mitigation

Should a new wetland be created and evaluated before anyone is allowed to destroy the wetland it is supposed to replace? Explain.

CASE STUDY

Can We Restore the Florida Everglades?

South Florida's Everglades was once a 100-kilometer-wide (62-mile-wide), knee-deep sheet of water flowing slowly south from Lake Okeechobee to Florida Bay (Figure 11.19, red dashed lines). As this shallow body of water—known as the "River of Grass"—trickled south, it created a vast network of wetlands with a variety of wildlife habitats.

To help preserve the wilderness in the lower end of the Everglades system, in 1947 the U.S. government established Everglades National Park. However, this protection effort did not work—as conservationists had predicted—because of a massive water distribution and land development project to the north. Between 1962 and 1971, the U.S. Army Corps of Engineers transformed the wandering 166-kilometer-long (103-mile-long) Kissimmee River into a mostly straight 84-kilometer (52-mile) canal flowing into Lake Okeechobee (Figure 11.19, black dashed line). The

FIGURE 11.18 This human-created wetland is located near Orlando, Florida (USA).

canal provided flood control by speeding the flow of water, but it drained large wetlands north of Lake Okeechobee, which farmers then converted to grazing land.

This and other projects have provided south Florida's rapidly growing population with a reliable water supply and flood protection. However, much of the original Everglades has been drained, paved over, polluted by agricultural runoff, and invaded by a number of plant and animal species. The Everglades is now less than half its original size and much of it has dried out, leaving large areas vulnerable to summer wildfires.

The Everglades National Park is known for its astonishing biodiversity, and each year more than a million people from all over the world visit the park. However, its biodiversity has been decreasing, mostly because of habitat loss, pollution, and invasive species. About 90% of the wading birds in Everglades National Park have vanished and populations of many remaining wading bird species have dropped sharply. In addition, populations of vertebrates, from deer to turtles, are down 75–95%.

By the 1970s, state and federal officials recognized that this huge plumbing project was reducing populations of native plants and wildlife—a major source of tourism revenues for Florida. It was also cutting the water supply for the 5.8 million residents of south Florida. In 1990 Florida's state government and the U.S. government agreed on a plan for the world's largest ecological restoration project, known as the Comprehensive Everglades Restoration Plan. The U.S. Army Corps of Engineers is supposed to carry out this joint federal and state plan to partially restore the Everglades.

The project has several ambitious goals, including restoration of the curving flow of more than half of the Kissimmee River; removal of 400 kilometers (248 miles) of canals and levees that block natural water flows south of Lake Okeechobee; conversion of large areas of farmland to marshes; the creation of 18 large reservoirs and underground water storage areas to store water for the lower Everglades and for south Florida's population; and building a canal–reservoir system for catching the water now flowing out to sea and pumping it back into the Everglades.

Will this huge ecological restoration project work? It depends not only on the abilities of scientists and engineers but also on prolonged political and economic support from citizens, the state's powerful sugarcane and agricultural industries, and elected state and federal

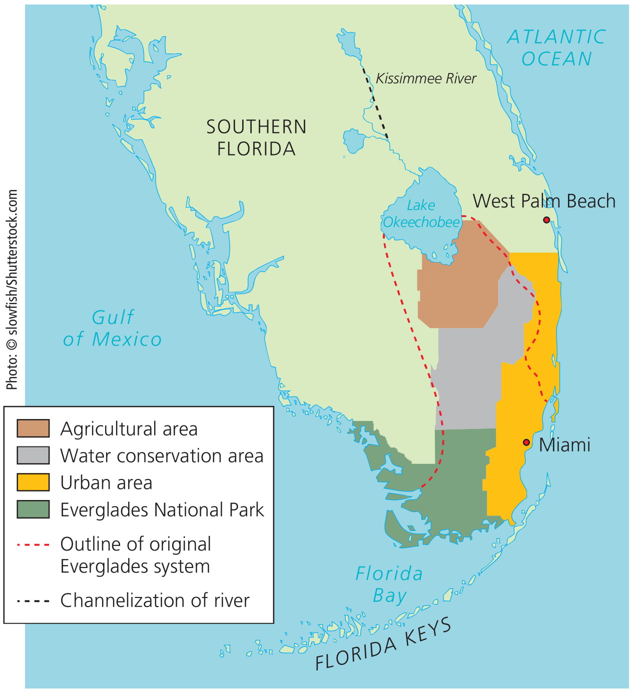

Photo: © slowfish/Shutterstock.com

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FIGURE 11.19 Florida's Everglades is the site of the world's largest ecological restoration project—an attempt to undo and redo an engineering project that has been destroying this vast wetland and threatening water supplies for south Florida's rapidly growing population.

officials. Some restrictions on phosphorus discharges from sugarcane plantations have been relaxed, which could worsen pollution problems. The project has also had cost overruns and funding shortages and is considerably behind schedule.

CONSIDER THIS . . .

THINKING ABOUT Everglades Restoration

Do you support carrying out the proposed plan for partially restoring the Florida Everglades, including making the federal government (taxpayers) responsible for half of the funding? Explain.

11.5 HOW SHOULD WE PROTECT AND SUSTAIN FRESHWATER LAKES, RIVERS, AND FISHERIES?

CONCEPT 11.5 Freshwater ecosystems are strongly affected by human activities on adjacent lands, and protection of these ecosystems must include protection of their watersheds.

Freshwater Ecosystems Are in Jeopardy

The ecosystem and economic services provided by many of the world's freshwater lakes, rivers, and fisheries are severely threatened by human activities (**Concept 11.5**). Currently, 40% of the freshwater fish species in North America are vulnerable, threatened, or endangered, according to a joint study by U.S., Canadian, and Mexican scientists.

Many of the world's freshwater wetlands have been destroyed. Aquatic species have been crowded out of at least half of the world's freshwater habitat areas and 40% of the world's rivers have been dammed or otherwise engineered. Invasive species, pollution, and climate change threaten the ecosystems of many lakes, rivers, and wetlands. Many freshwater fish stocks are overharvested and during this century, increasing human population pressure and climate change will intensify these threats.

Sustaining and restoring the biodiversity and ecosystem services provided by freshwater lakes and rivers is a complex and challenging task, as shown by the following Case Study.

CASE STUDY

Can the Great Lakes Survive Repeated Invasions by Alien Species?

Invasions by nonnative species are a major threat to the biodiversity and ecological functioning of many lakes, as illustrated by what has happened to the five Great Lakes, located on the border between the United States and Canada.

Collectively, the Great Lakes are the world's largest body of freshwater. Since the 1920s, these lakes have been invaded by at least 180 nonnative species and the number keeps rising. Many of the alien invaders arrive on the hulls of, or in bilge-water discharges of, oceangoing ships that have been entering the Great Lakes through the St. Lawrence Seaway since 1959.

One of the biggest threats, the *sea lamprey*, reached the westernmost Great Lakes as early as 1920. This parasite attaches itself to almost any kind of fish and kills the victim by sucking out its blood (Figure 5.7, p. 105). Over the years, it has depleted populations of many important sport fish species such as lake trout. The United States and Canada keep the lamprey population down by applying a chemical that kills lamprey larvae where they spawn in streams that feed the lakes—at a cost of about $15 million a year.

In 1986 larvae of the *zebra mussel* (Figure 9.9, p. 201) arrived in ballast water discharged from a European ship near Detroit, Michigan. This thumbnail-sized mollusk reproduces rapidly. It has displaced other mussel species and thus depleted the food supply for some other Great Lakes aquatic species. The mussels have also clogged irrigation pipes, shut down water intake pipes for power plants and city water supplies, fouled beaches, and jammed ships' rudders. They have grown in thick masses on many boat hulls, piers, and other exposed aquatic surfaces (Figure 11.20). It

FIGURE 11.20 These *zebra mussels* are attached to a water current meter in Lake Michigan.

FIGURE 11.21 *Asian carp* may be the next major invasive species to threaten the Great Lakes.

has also spread to freshwater communities in parts of southern Canada and 18 eastern U.S. states. Damages and attempts to control this mussel cost the two countries about $1 billion a year—an average of $114,000 per hour.

Sometimes, native species can help control a harmful invasive species. For example, populations of zebra mussels are declining in some parts of the Great Lakes because a native sponge growing on their shells is preventing them from opening up their shells to breathe. However, it is not clear whether the sponges will effectively control the invasive mussels and what harmful ecological effects the sponges might have.

In 1989 a larger and potentially more destructive species, the *quagga mussel*, invaded the Great Lakes, probably discharged in the ballast water of a Russian freighter. It can survive at greater depths and tolerate more extreme temperatures than the zebra mussel can. By 2009, scientists reported that quagga mussels had rapidly replaced many other bottom-dwellers in Lake Michigan. This has reduced the food supply for many fish and other species, thus leading to a major disruption of the lake's food web. There is concern that quagga mussels may spread by river transport and eventually colonize eastern U.S. ecosystems such as the Chesapeake Bay (see Case Study, p. 177) and waterways in parts of Florida.

The *Asian carp* (Figure 11.21) is the most recent threat to the Great Lakes system. In the 1970s, catfish farmers in the southern United States imported two species of Asian carp to help remove suspended matter and algae from their aquaculture farm ponds. Heavy flooding during the 1990s caused many of these ponds to overflow, which allowed some of the carp to enter the Mississippi River. After working their way up the Mississippi River system, these invaders are now close to entering Lake Michigan, if they have not already done so. Joel Brammeier, president of the Alliance for the Great Lakes, warned that "if Asian carp get into Lake Michigan, there is no stopping them."

These highly prolific fish can quickly grow as long as 1.2 meters (4 feet) and weigh up to 50 kilograms (110 pounds). They can eat as much as 20% of their own body weight in plankton every day, which can disrupt lake food webs. When startled they jump clear of the water, and several boaters have been hit and injured by jumping carp. These fish have no natural predators in the rivers they have invaded or in the Great Lakes.

Federal, state, and local agencies are developing plans to prevent the Asian carp from reaching and spreading throughout the Great Lakes, which would threaten the lakes' $7 billion-a-year fishing industry. Proposed measures include electric barriers to limit access through rivers flowing into the Great Lakes and laws to prevent the transporting of fish across state borders. In addition, some chemical companies are developing carp-specific poisons.

Managing River Basins Is Complex and Controversial

Rivers and streams provide important ecosystem services (Figure 11.22), but overfishing, pollution, dams, and water withdrawal for irrigation are disrupting these services. Currently, these ecosystem services are given little or no monetary value when the costs and benefits of dam and reservoir projects are assessed. According to environmental economists, attaching even crudely estimated monetary values to these ecosystem services—an application of the full-cost pricing **principle of sustainability**—would help to sustain them.

An example of such disruption and loss of freshwater biodiversity is what happened in the Columbia River, which runs through parts of southwestern Canada and the northwestern United States. It has 119 dams, 19 of which are major generators of inexpensive hydroelectric power. It also supplies water for major urban areas and large irrigation projects.

The Columbia River dams have benefited many people, but have also sharply reduced populations of wild salmon. These migratory fish hatch in the upper reaches of the streams and rivers that form the headwaters of the Columbia River, migrate to the ocean where they spend most of their adult lives, and then swim upstream to return to the place where they were hatched to spawn and die. Dams interrupt their life cycle by interfering with the migration of young fish downstream, and blocking the return of mature fish attempting to swim upstream to their spawning grounds.

Since the dams were built, the Columbia River's wild Pacific salmon population has dropped by 94% and nine of the Pacific Northwest salmon species are listed as endangered or threatened. Since 1980, the U.S. federal government has spent more than $3 billion in efforts to save the salmon, with little success.

Natural Capital

Ecosystem Services of Rivers

- Deliver nutrients to sea to help sustain coastal fisheries
- Deposit silt that maintains deltas
- Purify water
- Renew and renourish wetlands
- Provide habitats for wildlife

FIGURE 11.22 Rivers and streams provide some important ecosystem services. ***Critical thinking:*** Which two of these services do you think are the most important? Why?

Protecting Watersheds

Sustaining freshwater aquatic systems begins with understanding that land and water are connected. For example, lakes and streams receive many of their nutrients from the ecosystems of bordering land. Such nutrient inputs come from falling leaves, animal feces, and pollutants generated by people, all of which are washed into bodies of water by rainstorms and melting snow. Therefore, to protect a stream or lake from excessive inputs of nutrients and pollutants, we must protect its watershed (**Concept 11.5**).

As with marine systems, freshwater ecosystems can be protected through laws, economic incentives, and restoration efforts. For example, restoring and sustaining the ecosystem and economic services of rivers will probably require taking down some dams and restoring river flows. In addition, some scientists and politicians call for protecting all remaining free-flowing rivers by prohibiting the construction of new dams.

In 1968 the U.S. Congress passed the National Wild and Scenic Rivers Act to establish protection of rivers with outstanding wildlife, geological, scenic, recreational, historical, or cultural values. The law classified *wild rivers* as those that are relatively inaccessible (except by trail), and *scenic rivers* as rivers of great scenic value that are free of dams, mostly undeveloped, and accessible in only a few places by roads. These rivers are now protected from widening, straightening, dredging, filling, and damming. However, the Wild and Scenic Rivers System keeps only 3% of U.S. rivers free flowing and protects less than 1% of the country's total river length.

Protecting Freshwater Fisheries

Sustainable management of freshwater fisheries involves supporting populations of commercial and sport fish species, preventing such species from being overfished, and reducing or eliminating populations of harmful invasive species. The traditional approach to managing freshwater fish species is to regulate the time and length of fishing seasons and the number and size of fish that can be taken.

Other techniques include building reservoirs, ponds, and stocking them with fish and protecting and creating fish spawning sites. In addition, some fishery managers try to protect fish habitats from sediment buildup and other forms of pollution. They also work to prevent or reduce large human inputs of plant nutrients that spur the excessive growth of aquatic plants.

Some fishery managers seek to control predators, parasites, and diseases by improving habitats, breeding genetically resistant fish varieties, and using antibiotics and disinfectants. Hatcheries can be used to restock ponds, lakes, and streams with prized species such as trout, and entire river basins can be managed to protect valued species such as salmon.

11.6 WHAT SHOULD BE OUR PRIORITIES FOR SUSTAINING AQUATIC BIODIVERSITY?

CONCEPT 11.6 Sustaining the world's aquatic biodiversity requires mapping it, protecting aquatic hotspots, creating large and fully protected marine reserves, protecting freshwater ecosystems, and restoring degraded coastal and inland wetlands.

Using an Ecosystem Approach to Sustain Aquatic Biodiversity and Ecosystem Services

Edward O. Wilson (see Individuals Matter 4.1, p. 81) and other biodiversity experts have proposed the following priorities for an ecosystem approach to sustaining aquatic biodiversity and ecosystem services (**Concept 11.6**):

- Map and inventory the world's aquatic biodiversity.
- Identify and preserve the world's aquatic biodiversity hotspots and areas where deteriorating ecosystem services threaten people and many forms of aquatic life.
- Create large and fully protected marine reserves to allow damaged marine ecosystems to recover and to allow fish stocks to be replenished.
- Protect and restore the world's lakes and river systems, which are among the world's most threatened ecosystems, but emphasize pollution prevention because ecological restorations are expensive and have a high failure rate.
- Initiate worldwide ecological restoration projects in systems such as coral reefs and inland and coastal wetlands.
- Find ways to raise the incomes of people who live on or near protected waters so that they can become partners in the protection and sustainable use of aquatic ecosystems.

There is growing evidence that the current harmful effects of human activities on aquatic biodiversity and ecosystem services could be reversed over the next two decades. Doing this will require implementing an ecosystem approach to sustaining both terrestrial and aquatic ecosystems. According to Edward O. Wilson, such a conservation strategy would cost about $30 billion per year—an amount that could be provided by a tax of one penny per cup of coffee consumed in the world each year.

CONSIDER THIS . . .

THINKING ABOUT The Cost of Sustaining Ecosystems

Would you be willing to pay an extra penny for each cup of coffee you buy to help pay for sustaining ecosystems and biodiversity? Can you think of other things for which you would pay a little more for this effort?

This strategy for protecting the earth's vital biodiversity and ecosystem services will not be implemented without bottom-up political pressure on elected officials from individual citizens and groups. It will also require cooperation among scientists, engineers, and business and government leaders in applying the win-win **principle of sustainability**.

A key part of this strategy will be for individuals to "vote with their wallets" by trying to buy only products and services that do not have harmful impacts on terrestrial and aquatic biodiversity. For example, we can eat lower on the aquatic food chain by choosing plant-eating species such as tilapia, carp, and catfish instead of carnivorous species such as salmon, shrimp, and sea bass. The highly respected Monterey Bay Aquarium publishes and regularly updates a simple sustainable seafood guide called *Seafood Watch* that can be viewed at their website or with a free mobile phone app.

According to Sylvia Earle (Individuals Matter 11.1), failure to act now "means that in 50 years there may be no coral reefs and no commercial fishing, because the fish will simply be gone. . . . Imagine what that means to our life-support system."

BIG IDEAS

- The world's aquatic systems provide important economic and ecosystem services, and scientific investigation of these poorly understood ecosystems could lead to immense ecological and economic benefits.
- Aquatic ecosystems and fisheries are being severely degraded by human activities that lead to aquatic habitat disruption and loss of biodiversity.
- We can sustain aquatic biodiversity by establishing protected sanctuaries, managing coastal development, reducing water pollution, and preventing overfishing.

Tying It All Together

Invading Jellyfish and Aquatic Sustainability

This chapter began with a look at populations of a number of jellyfish species that are exploding, disrupting marine food webs, and taking over parts of the ocean (**Core Case Study**). Throughout the chapter, we examined how loss of aquatic habitats, invasive species, population pressures, climate change, ocean acidification, and overexploitation are harming many marine and freshwater aquatic species. We looked at how many of the world's fisheries are being depleted. We discussed why jellyfish populations are exploding and why this is a serious threat.

We also explored possible solutions to these problems, including the jellyfish invasions. We know that when areas of the oceans are left undisturbed, marine ecosystems tend to recover their natural functions, and fish populations can rebound quickly. In addition, the best approach to sustaining freshwater biodiversity is to use an ecosystem approach.

We can achieve greater success in sustaining aquatic biodiversity by applying the three **scientific principles of sustainability**. This means reducing inputs of sediments and excess nutrients, which cloud water, lessen the input of solar energy, and upset aquatic food webs and the natural cycling of nutrients in aquatic systems. It also means valuing aquatic biodiversity and putting a high priority on preserving the biodiversity and ecosystem services of aquatic systems. Applying the full-cost pricing, win-win, and ethical **principles of sustainability** can help us to achieve these goals.

Chapter Review

Core Case Study

1. What are jellyfish? What problems are they causing?

Section 11.1

2. What is the key concept for this section? How much do we know about the habitats and species that make up the earth's aquatic biodiversity? What are three general patterns of marine biodiversity? Give six reasons for caring about marine biodiversity. What are the six major threats to aquatic diversity and ecosystems as summarized by the acronym HIPPCO? How have coral reefs been threatened? What is **coral bleaching** and what causes it? How can sunscreen lotion harm coral reefs? What is the state of the world's mangrove forests, sea-grass beds, and ocean-bottom habitats? What is **ocean acidification**? What causes it, what are its projected harmful effects on ocean life, and how could we reduce these threats?

3. Describe the harmful effects of the marine invasive species known as the lionfish. What are two harmful effects on aquatic systems resulting from the growth of the human population in coastal areas? Give two examples of how pollution is affecting aquatic systems. What are "dead zones" and how do they form? What is the threat from toxic mercury? What are three ways in which projected climate change could threaten aquatic biodiversity?

4. Define **fishery**. What are three major harmful effects of overfishing? Describe the effects of trawler fishing, purse-seine fishing, long-lining, and drift-net fishing. What is **bycatch**? What is a **fishprint**? What percentage of the world's commercial fisheries are fully exploited, overexploited, or depleted? Summarize the story of the collapse of the Atlantic cod fishery. What is happening to the world's large, predatory fishes and why does it matter? What are the harmful effects of the fishing industry's shifting to lower trophic levels of marine food webs? Summarize the arguments for protecting sharks. Summarize efforts to protect whales from overharvesting and extinction. Describe the status of sea turtles and explain how human activities are threatening their existence. Why are jellyfish populations growing and what difference does this make? How could we prevent them from taking over much of the ocean?

Section 11.2

5. What is the key concept for this section? List three reasons why it is difficult to protect marine biodiversity. How have laws and treaties been used to help sustain

aquatic species? What is the main obstacle to enforcement of international agreements? How can economic incentives help to sustain aquatic biodiversity? Give an example of how this can happen.

6. Explain how marine protected areas (MPAs) and marine reserves can help sustain aquatic biodiversity and ecosystem services. What percentage of the world's oceans is strictly protected from harmful human activities in marine reserves? What percentage should be strictly protected, according to marine scientists? Summarize the contributions of Sylvia Earle to the protection of aquatic biodiversity. Give two examples of how marine systems can be restored. Describe the roles of fishing communities and individual consumers in regulating fishing and coastal development. Describe Japan's attempt to restore its largest coral reef. What is integrated coastal management?

Section 11.3

7. What is the key concept for this section? Describe three ways of estimating the sizes of fish populations and list their limitations. How can the precautionary principle be applied in managing fisheries and large marine systems? What are catch-share and co-management systems and how can they help to sustain fisheries? How can government subsidies encourage overfishing? Explain how consumer choices can help to sustain fisheries, aquatic biodiversity, and ecosystem services. List five ways to manage global fisheries more sustainably.

Section 11.4

8. What is the key concept for this section? What percentage of the U.S. coastal and inland wetlands has been destroyed since 1900? What are the major threats to wetlands and their ecosystem services? How does the United States attempt to reduce wetland losses? What is wetlands mitigation? Summarize the story of efforts to restore the Florida Everglades.

Section 11.5

9. What is the key concept for this section? Describe the major threats to the world's rivers and other freshwater systems. Explain how invasions by nonnative species are threatening the Great Lakes. What are some ways to help sustain river systems? What are three ways to protect freshwater habitats and fisheries?

Section 11.6

10. What is the key concept for this section? List six priorities for applying the ecosystem approach to sustaining aquatic biodiversity. What are this chapter's three big ideas? How can we apply the three **scientific principles of sustainability** in efforts to control populations of jellyfish (**Core Case Study**) and thus help sustain aquatic biodiversity and ecosystem services?

Note: Key terms are in bold type.

Critical Thinking

1. Why should you be concerned about jellyfish populations taking over large areas of the world's oceans? Why are jellyfish considered to be indicator species (see p. 83)?

2. What do you think are the three greatest threats to aquatic biodiversity? For each of them, explain your thinking.

3. Overall, why are aquatic species more vulnerable to extinction hastened by human activities than terrestrial species are?

4. How might continued overfishing of marine species affect your life? How could it affect the lives of any children or grandchildren you might have? What are three things you could do to help prevent overfishing?

5. Should fishers who harvest fish from a country's publicly owned waters be required to pay the government fees for the fish they catch? Explain. If your livelihood depended on commercial fishing, would you be for or against such fees?

6. Why do you think no-fishing marine reserves recover their biodiversity faster and more effectively than do protected areas where fishing is allowed but restricted? Explain.

7. Some scientists consider ocean acidification to be one of the most serious environmental and economic threats that the world faces. How do you contribute to ocean acidification in your daily life? What would you do to help reduce the threat of ocean acidification?

8. How might your life and the lives of any children or grandchildren you might have be affected if we fail to control the spread of jellyfish populations? What are three things you could do to help prevent this from happening?

Doing Environmental Science

Pick a coastal area, river, stream, lake, or wetland near where you live and research and write a brief account of its history. Then survey and take notes on its present condition. Has its condition improved or deteriorated during the last 10 years? What governmental or private efforts are being used to protect this aquatic system? Write a report summarizing your findings. Based on your report along with your ecological knowledge of this system, write up some recommendations to policy makers for protecting it. Try presenting your recommendations to one or more local policy makers.

Global Environment Watch Exercise

Go to your MindTap course to access the GREENR database. Starting on the home page, under "Browse Issues and Topics", click on *Environment and Ecology*, then select *Coral Reefs*. Use this topic portal to do the following: **(a)** identify two cases of coral reef degradation—one where the reef continues to be degraded and one where a degraded reef is being restored; **(b)** for each case, list the main causes for this degradation; **(c)** for each case, describe any efforts to protect or restore the reef; and **(d)** for each case, give your best estimation of whether the reef will survive and explain your reasoning.

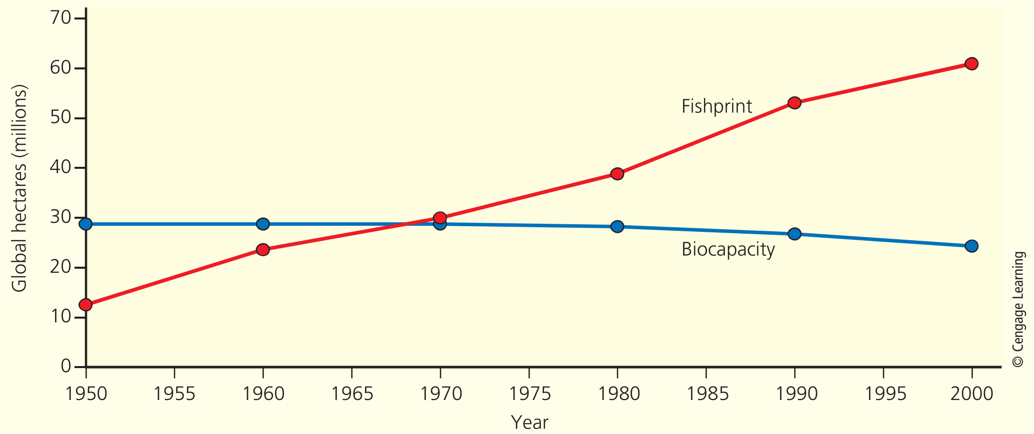
Ecological Footprint Analysis

A fishprint provides a measure of a country's fish harvest in terms of area. The unit of area used in fishprint analysis is the global hectare (gha), a unit weighted to reflect the relative ecological productivity of the area fished. When compared with the fishing area's *sustainable biocapacity* (its ability to provide a stable supply of fish year after year, expressed in terms of yield per area), its fishprint indicates whether the country's annual fishing harvest is sustainable. The fishprint and biocapacity are calculated using the following formulas:

Fishprint in (gha) = metric tons of fish harvested per year/productivity in metric tons per hectare × weighting factor

Biocapacity in (gha) = sustained yield of fish in metric tons per year/productivity in metric tons per hectare × weighting factor

The following graph shows the earth's total fishprint and biocapacity. Study it and answer the questions that follow.



1. Based on the graph,
   a. What was the status of the global fisheries with respect to sustainability in 2000?
   b. In what year did the global fishprint begin to exceed the biological capacity of the world's oceans?
   c. By how much did the global fishprint exceed the biological capacity of the world's oceans in 2000?
2. Assume a country harvests 18 million metric tons of fish annually from an ocean area with an average productivity of 1.3 metric tons per hectare and a weighting factor of 2.68. What is the annual fishprint of that country?
3. If biologists determine that this country's sustained yield of fish is 17 million metric tons per year,
   a. What is the country's sustainable biological capacity?
   b. Is the county's annual fishing harvest sustainable?
   c. To what extent, as a percentage, is the country undershooting or overshooting its biological capacity?