# Sustaining Aquatic Biodiversity

11

## A Biological Roller Coaster Ride in Lake Victoria

CORE CASE STUDY

Lake Victoria, a large, shallow lake in East Africa (Figure 11-1), has been in ecological trouble for more than 2 decades.

Until the early 1980s, the lake had 500 species of fish found nowhere else. About 80% of them were small fish known as cichlids (pronounced "SIK-lids"), which feed mostly on detritus, algae, and zooplankton. Since 1980, some 200 of the cichlid species have become extinct, and some of those that remain are in trouble.

Several factors caused this dramatic loss of aquatic biodiversity. First, there was a large increase in the population of the Nile perch (Figure 11-2). This large predatory fish was deliberately introduced into the lake during the 1950s and 1960s to stimulate exports of the fish to several European countries, despite warnings by biologists that this huge fish with a big appetite would reduce or eliminate many defenseless native fish species. The population of this large and prolific fish exploded, devoured the cichlids and by 1986 had wiped out over 200 cichlid species.

Introducing the perch had other social and ecological effects. The new mechanized fishing industry increased poverty and malnutrition by putting most small-scale fishers and fish vendors out of business. And because the oily flesh of the perch are preserved by use of a wood smoker, local forests were depleted for firewood.

Another factor in loss of biodiversity in Lake Victoria was frequent algal blooms. These blooms became more common in the 1980s, due to nutrient runoff from surrounding farms and deforested land, spills of untreated sewage, and declines in the populations of algae-eating cichlids.

Also, the Nile perch population is decreasing because it severely reduced its own food supply of smaller fishes—an example of one of the four **scientific principles of sustainability** (see back cover) in action—and it also shows signs of being overfished. This may allow a gradual increase in the populations of some of the remaining cichlids.

This ecological story about the dynamics of large aquatic systems illustrates that there are unintended consequences when we intrude into a poorly understood ecosystem.

This chapter is devoted to helping us to understand the threats to aquatic biodiversity and what we can do to help sustain this vital part of the earth's natural capital.


**Figure 11-1** Lake Victoria is a large lake in East Africa.

Courtesy of the African Angler

**Figure 11-2 Natural capital degradation:** the Nile perch is a fine food fish that can weigh more than 91 kilograms (200 pounds). However, this deliberately introduced fish has played a key role in a major loss of biodiversity in East Africa's Lake Victoria (left).

## Key Questions and Concepts

**11-1** **What are the major threats to aquatic biodiversity?**

**CONCEPT 11-1** Aquatic species are threatened by habitat loss, invasive species, pollution, climate change, and overexploitation, all made worse by the growth of the human population.

**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 using community-based integrated coastal management.

**11-3** **How should we manage and sustain marine fisheries?**

**CONCEPT 11-3** Sustaining marine fisheries will require improved monitoring of fish populations, cooperative fisheries management among communities and nations, reduction of fishing subsidies, and careful consumer choices in seafood markets.

**11-4** **How can we protect and sustain wetlands?**

**CONCEPT 11-4** To maintain the ecological and economic services of wetlands, we must maximize preservation of remaining wetlands and restoration of degraded and destroyed wetlands.

**11-5** **How can we protect and sustain freshwater lakes, rivers, and fisheries?**

**CONCEPT 11-5** Freshwater ecosystems are strongly affected by human activities on adjacent lands, and protecting these ecosystems must include protection of their watersheds.

**11-6** **What should be our priorities for sustaining biodiversity and ecosystem services?**

**CONCEPT 11-6** Sustaining the world's biodiversity and ecosystem services will require mapping terrestrial and aquatic biodiversity, maximizing protection of undeveloped terrestrial and aquatic areas, and carrying out ecological restoration projects worldwide.

*Note:* Supplements 2 (p. S4), 8 (p. S47), and 13 (p. S78) can be used with this chapter.

*The coastal zone may be the single most important portion of our planet. The loss of its biodiversity may have repercussions far beyond our worst fears.*

G. CARLETON RAY

# 11-1 What Are the Major Threats to Aquatic Biodiversity?

▶ **CONCEPT 11-1 Aquatic species are threatened by habitat loss, invasive species, pollution, climate change, and overexploitation, all made worse by the growth of the human population.**

## We Have Much to Learn about Aquatic Biodiversity

Although we live on a watery planet, we have explored only about 5% of the earth's global ocean (Figure 8-2, p. 163) and know relatively little about its biodiversity and how it works. We also have limited knowledge about freshwater biodiversity.

However, scientists have observed three general patterns of marine biodiversity. *First,* the greatest marine biodiversity occurs in coral reefs (Chapter 8 Core Case Study, p. 162), estuaries, and the deep-ocean floor. *Second,* biodiversity is higher near coasts than in the open sea because of the greater variety of producers and habitats in coastal areas (Figure 8-5, p. 166). *Third,* biodiversity is higher in the bottom region of the ocean than in the surface region because of the greater variety of habitats and food sources on the ocean bottom.

The world's marine systems provide important ecological and economic services (Figure 8-4, p. 165). Thus, scientific investigation of poorly understood marine aquatic systems is a *research frontier* that could lead to



**Links:** CORE CASE STUDY refers to the Core Case Study. SUSTAINABILITY refers to the book's sustainability theme. CONCEPT LINK indicates links to key concepts in earlier chapters.

immense ecological and economic benefits. Freshwater systems, which occupy only 1% of the earth's surface, also provide important ecological and economic services (Figure 8-14, p. 174).

**RESEARCH FRONTIERS**

Exploring marine and freshwater ecosystems, their species, and species interactions. See **academic.cengage.com/biology/miller**.

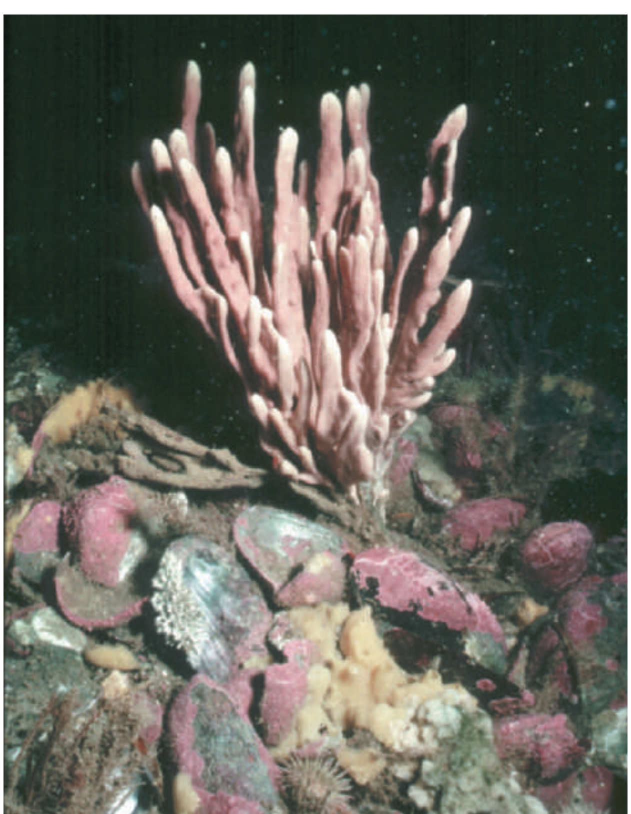
## Human Activities Are Destroying and Degrading Aquatic Habitats

As with terrestrial biodiversity, the greatest threats to the biodiversity of the world's marine and freshwater ecosystems (**Concept 11-1**) can be remembered with the aid of the acronym HIPPCO, with H standing for *habitat loss and degradation.* Some 90% of fish living in the ocean spawn in coral reefs (Figure 4-10, left, p. 89, and Figure 8-1, p. 162), mangrove forests (Figure 8-8, p. 168), coastal wetlands (Figure 8-7, p. 167), or rivers (Figure 8-17, p. 176). And these areas are under intense pressure from human activities (Figure 8-12, p. 172). Scientists reported in 2006 that these coastal habitats are disappearing at rates 2–10 times higher than the rate of tropical forest loss.

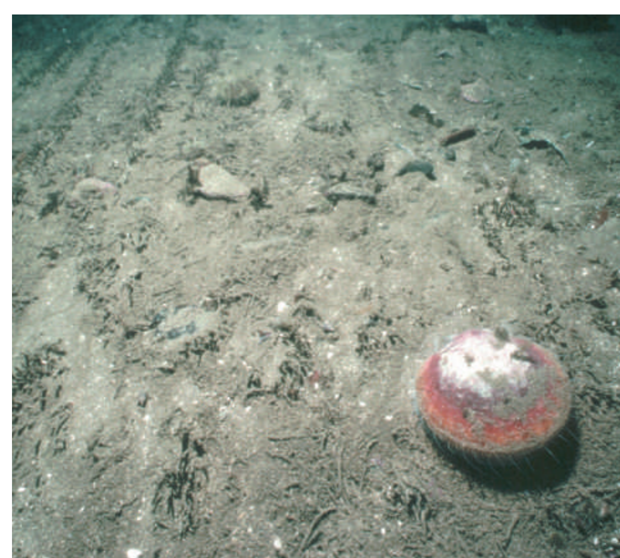
A major threat is loss and degradation of many sea-bottom habitats by dredging operations and trawler fishing boats. Trawlers drag huge nets weighted down with heavy chains and steel plates like giant submerged bulldozers over ocean bottoms to harvest a few species of bottom fish and shellfish (Figure 11-3). Trawling nets reduce coral reef habitats to rubble and kill a variety of creatures on the bottom by crushing them, burying them in sediment, and exposing them to predators. Each year, thousands of trawlers scrape and disturb an area of ocean floor about 150 times larger than the area of forests that are clear-cut annually.

In 2004, some 1,134 scientists signed a statement urging the United Nations to declare a moratorium on bottom trawling on the high seas by 2006 and to eliminate it globally by 2010. Fishing nations led by Iceland, Russia, China, and South Korea blocked such a ban. But in 2007, those countries (except for Iceland) and 18 others agreed to voluntary restrictions on bottom trawling in the South Pacific. The agreement will partially protect about one-quarter of the world's ocean bottom but monitoring and enforcement will be difficult.

Habitat disruption is also a problem in freshwater aquatic zones. Dams and excessive water withdrawal from rivers and lakes (mostly for agriculture) destroy aquatic habitats and water flows and disrupt freshwater biodiversity. As a result of these and other human activities, 51% of freshwater fish species—more than any other major type of species—are threatened with premature extinction (Figure 9-6, p. 189).



Peter J. Auster/National Undersea Research Center



Peter J. Auster/National Undersea Research Center

**Figure 11-3 Natural capital degradation:** area of ocean bottom before (left) and after (right) a trawler net scraped it like a gigantic plow. These ocean floor communities 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." Trawler fishers claim that ocean bottom life recovers after trawling and that they are helping to satisfy the increasing consumer demand for fish. **Question:** What land activities are comparable to this?

## Invasive Species Are Degrading Aquatic Biodiversity

Another problem is the deliberate or accidental introduction of hundreds of harmful invasive species—the I in HIPPCO—(Figure 9-14, p. 199) into coastal waters, wetlands, and lakes throughout the world (**Concept 11-1**). These bioinvaders can displace or cause the extinction of native species and disrupt ecosystem services. For example, since the late 1980s, Lake Victoria (**Core Case Study**) has been invaded by the water hyacinth (Figure 11-4). This rapidly growing plant has carpeted large areas of the lake, blocked sunlight, deprived fish and plankton of oxygen, and reduced aquatic plant diversity.

CORE CASE STUDY

**THINKING ABOUT**
**The Nile Perch and Lake Victoria**

CORE CASE STUDY

Would most of the now extinct cichlid fish species in Lake Victoria (**Core Case Study**) still exist today if the Nile perch had not been introduced? Or might other factors come into play? Explain.

According to a 2008 study by The Nature Conservancy, 84% of the world's coastal waters are being colonized by invasive species. Bioinvaders are blamed for about two-thirds of fish extinctions in the United States between 1900 and 2000. They cost the country an average of about $14 million *per hour*. Many of these invaders arrive in the ballast water stored in tanks in large cargo ships to keep them stable. These ships take in ballast water—along with whatever microorganisms and tiny species it contains—in one harbor and dump it in another.

Consumers also introduce invasive species. For example, the *Asian swamp eel* has invaded the waterways of south Florida (USA), probably from the dumping of a home aquarium. This rapidly reproducing eel eats almost anything—including many prized fish species—by sucking them in like a vacuum cleaner. It can elude cold weather, drought, and predators by burrowing into mud banks. It is also resistant to waterborne poisons because it can breathe air, and it can wriggle across dry land to invade new waterways, ditches, canals, and marshes. Eventually, this eel could take over much of the waterways of the southeastern United States.

Another example is the *purple loosestrife*, a perennial plant that grows in wetlands in parts of Europe. Since the 1880s, it has been imported and used in gardens as an ornamental plant in many parts of the world. A single plant can produce more than 2.5 million seeds a year, which are spread by flowing water and by becoming attached to wildlife, livestock, hikers, and vehicle tire treads. It reduces wetland biodiversity by displacing native vegetation and reducing habitat for some forms of wetland wildlife.

Some U.S. states have recently introduced two natural predators of loosestrife from Europe: a weevil species and a leaf-eating beetle. It will take some time to determine the effectiveness of this biological control approach and to be sure the introduced predators themselves do not become pests.

While threatening native species, invasive species can also disrupt and degrade whole ecosystems. This is the focus of study for a growing number of researchers (Science Focus, at right).

Courtesy of Patrick Agaba and Clean Lakes, Inc.

**Figure 11-4** *Invasive water hyacinths,* supported by nutrient runoff, clogged a ferry terminal on the Kenyan part of Lake Victoria in 1997. By blocking sunlight and consuming oxygen, this invasion has reduced biodiversity in the lake. Scientists reduced the problem at strategic locations by mechanical removal and by introducing two weevils for biological control of the hyacinth.

## Population Growth and Pollution Can Reduce Aquatic Biodiversity

The U.N. Environment Programme (UNEP) projects that, by 2020, 80% of the world's people will be living along or near the coasts, mostly in gigantic coastal cities. This coastal population growth—the first P in HIPPCO—will add to the already intense pressure on the world's coastal zones, primarily by destroying more aquatic habitat and increasing pollution (**Concept 11-1**).

A 2008 study by Benjamin S. Halpern and other scientists found that only 4% of the world's oceans are not affected by pollution—the second P in HIPPCO—and 40% are strongly affected. In 2004, the UNEP estimated that 80% of all ocean pollution comes from land-based coastal activities. Humans have doubled the flow of nitrogen, mostly from nitrate fertilizers, into the oceans since 1860, and the 2005 Millennium Ecosystem Assessment estimated that this flow will increase by another two-thirds by 2050. These inputs of nitrogen (and similar inputs of phosphorus) result in eutrophication

## SCIENCE FOCUS

### How Carp Have Muddied Some Waters

Lake Wingra lies within the city of Madison, Wisconsin (USA), surrounded mostly by a forest preserve. While almost all of its shoreline is undeveloped, the lake receives excessive nutrient inputs from runoff, containing fertilizers from area farms and lawns, and storm water flowing in from city streets and parking lots. Its waters are green and murky throughout the warmer months of the year.

Lake Wingra also contains a number of invasive plant and fish species, including purple loosestrife and common carp. The carp, which were introduced in the late 1800s, now make up about half of the fish biomass in the lake. They devour algae called chara, which would normally cover the lake bottom and stabilize sediments. Consequently, fish movements and currents 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 works 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 with the carp gone, 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 the shallow shoreline waters.

Lathrop and his colleagues built a *fish exclosure* by installing a thick, heavy vinyl curtain around a 1-hectare (2.5-acre), square-shaped perimeter extending out from the shore (Figure 11-A). This barrier hangs 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 one month, the waters within the exclosure were noticeably clearer, and within a year, the difference in clarity was dramatic, as Figure 11-A shows.


**Figure 11-A** *Lake Wingra* in Madison, Wisconsin (USA) has become eutrophic largely because of the introductions of invasive species, including the common carp, which now represents half of the fish biomass in the lake. Removal of carp in the experimental area shown here resulted in a dramatic improvement in the clarity of the water and subsequent regrowth of native plant species in shallow water.

In 2008, the scientists began removing carp from the rest of the lake. Lathrop notes that keeping carp out of Lake Wingra will be a daunting task, 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 way to avoid such effects.

#### Critical Thinking

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

of marine and freshwater systems, which can lead to algal blooms (Figure 8-16, right, p. 175), fish die-offs, and degradation of ecosystem services.

In Lake Victoria, such eutrophication was a key development in the takeover by invasive Nile perch and the loss of cichlid populations, as described in the **Core Case Study**. With increased runoff generated by the growing human population in nearby towns and farms came algal blooms. Because cichlids feed on algae, their populations rose dramatically. Before Nile perch were introduced, such population explosions would have ended in die-offs of the cichlids. But the Nile perch suddenly had a bigger food supply, and thus their population grew and led to changes in the lake's ecosystem and all the resulting problems.

CORE CASE STUDY

Similar pressures are growing in freshwater systems, as more people seek homes and places for recreation near lakes and streams. The result is massive inputs of sediment and other wastes from land into these aquatic systems.

Toxic pollutants from industrial and urban areas can kill some forms of aquatic life by poisoning them. And each year, plastic items dumped from ships and left as litter on beaches kill up to 1 million seabirds and 100,000 mammals and sea turtles. Such pollutants and debris threaten the lives of millions of marine mammals (Figure 11-5, p. 254) and countless fish that ingest, become entangled in, or are poisoned by them. These forms of pollution lead to an overall reduction in aquatic biodiversity and degradation of ecosystem services.


**Figure 11-5** This Hawaiian monk seal was slowly starving to death before this discarded piece of plastic was removed from its snout. Each year, plastic items dumped from ships and left as litter on beaches threaten the lives of millions of marine mammals, turtles, and seabirds that ingest, become entangled in, or are poisoned by such debris.

## Climate Change Is a Growing Threat

Climate change—the C in HIPPCO—threatens aquatic biodiversity (**Concept 11-1**) and ecosystem services partly by causing sea levels to rise. During the past 100 years, average sea levels have risen by 10–20 centimeters (4–8 inches), and scientists estimate they will rise another 18–59 centimeters (0.6–1.9 feet) and perhaps as high as 1–1.6 meters (3.2–5.2 feet) between 2050 and 2100 mostly, because of projected global warming. This would destroy more coral reefs, swamp some low-lying islands, drown many highly productive coastal wetlands, and put much of the U.S. state of Louisiana's coast, including New Orleans, under water (Figure 8-18, p. 177). And some Pacific island nations could lose more than half of their protective coastal mangrove forests by 2100, according to a 2006 study by UNEP (Science Focus, at right). See *The Habitable Planet,* Video 5, at **www.learner.org/resources/series209.html** for projected sea level changes in densely populated coastal areas such as Vietnam and New York City.

## Overfishing and Extinction: Gone Fishing, Fish Gone

Overfishing—the O in HIPPCO—is not new. Archaeological evidence indicates that for thousands of years, humans living in some coastal areas have overharvested fishes, shellfish, seals, turtles, whales, and other marine mammals (**Concept 11-1**). But today's industrialized fishing fleets can overfish much more of the oceans and deplete marine life at a much faster rate. Today, fish are hunted throughout the world's oceans by a global fleet of millions of fishing boats—some of them longer than a football field. Modern industrial fishing can cause 80% depletion of a target fish species in only 10–15 years (Case Study, p. 256).

The human demand for seafood is outgrowing the sustainable yield of most ocean fisheries. To keep consuming seafood at the current rate, we will need 2.5 times the area of the earth's oceans, according to the *Fishprint of Nations 2006,* a study based on the concept of the human ecological footprint (**Concept 1-3**, p. 12, and Figure 1-10, p. 15). The **fishprint** is defined as the area of ocean needed to sustain the consumption of an average person, a nation, or the world. The study found that all nations together are overfishing the world's global oceans by an unsustainable 157%.

CONCEPT LINK

In most cases, overfishing leads to *commercial extinction,* which occurs when it is no longer profitable to continue fishing the affected species. Overfishing usually results in only a temporary depletion of fish stocks, as long as depleted areas and fisheries are allowed to recover. But as industrialized fishing fleets vacuum up more and more of the world's available fish and shellfish, recovery times for severely depleted populations are increasing and can take 2 decades or more. In 1992, for example, Canada's 500-year-old Atlantic cod fishery off the coast of Newfoundland collapsed and was closed. This put at least 20,000 fishers and fish processors out of work and severely damaged Newfoundland's economy. As Figure 11-6 shows,

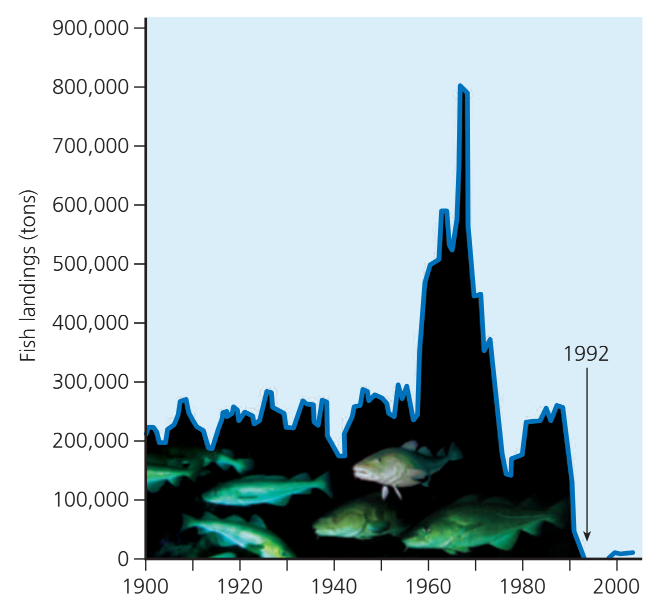



**Figure 11-6 Natural capital degradation:** this graph illustrates the collapse of the cod fishery in the northwest Atlantic off the Canadian coast. Beginning in the late 1950s, fishers used bottom trawlers to capture more of the stock, reflected in the sharp rise in this graph. This resulted in extreme overexploitation of the fishery, which began a steady fall throughout the 1970s, followed by a slight recovery in the 1980s and total collapse by 1992 when the site was closed to fishing. Canadian attempts to regulate fishing through a quota system had failed to stop the sharp decline. The fishery was reopened on a limited basis in 1998 but then closed indefinitely in 2003. (Data from Millennium Ecosystem Assessment)

## SCIENCE FOCUS

### Sustaining Ecosystem Services by Protecting and Restoring Mangroves

Mangroves are not among the world's biodiversity hotspots and do not contain a large number of species, as do endangered tropical rain forests. However, they too require protection because of the important ecosystem services they provide for coastal dwellers.

For example, protecting mangroves and restoring them in areas where they have been destroyed are important ways to reduce the impacts of rising sea levels and more intense storm surges. These ecosystem services will become more important in the face of tropical storms, possibly becoming more intense as a result of global warming, and of tsunamis, caused mostly by earthquakes on ocean seafloors. Protecting and restoring these natural coastal barriers is also much cheaper than building concrete sea walls or moving threatened coastal towns and cities inland.

Indonesia, a sprawling nation of about 17,000 islands, is especially vulnerable to rising sea levels and storm surges. But decades of rampant development along its island coastlines have destroyed or degraded about 70% of its mangrove forests. Even so, Indonesia still has the world's largest area of mangroves, amounting to about one-fourth of the world's remaining mangrove forests. In the 1990s, it started a program to protect more of these areas and to restore large areas of degraded mangrove forests.

Expanding mangrove protection and restoration in Indonesia and in other nations will require educating citizens, government officials, and business leaders about the huge economic value of the natural ecosystem services they provide. These economic benefits should be considered during any decision-making process concerning development of these fragile coastal areas.

#### Critical Thinking

Do you agree that the estimated economic value of ecosystem services provided by mangroves should be considered in making coastal development decisions? If you agree, how would you accomplish this politically?

this cod population has not recovered, despite the fishing ban.

Such a collapse can create a domino effect, leading to collapses of other species. After the cod were fished out in the North Atlantic, fishers turned to sharks, which provide important ecosystem services and help to control the populations of other species (Case Study, p. 96). Since then, overfishing of big sharks has cut Atlantic stocks by 99%, according to a 2007 Canadian fisheries study. Scientists reported that with the large sharks essentially gone, the northwest Atlantic populations of rays and skates, which the sharks once fed on, have exploded and have wiped out most of the bay scallops.

One result of the increasingly efficient global hunt for fish is that big individuals in many populations of commercially valuable predatory species—including cod, salmon, mackerel, herring, and dogfish—are becoming scarce. And according to a 2003 study by conservation biologist Boris Worm and his colleagues, 90% or more of the large, predatory, open-ocean fishes such as tuna, swordfish, and marlin have disappeared since 1950 (see *The Habitable Planet,* Video 9, at **www.learner.org/resources/series209.html**). The large bluefin tuna, with a typical weight of 340 kilograms (750 pounds) and a length of 2 meters (6.5 feet), is the premier choice for sushi and sashimi, and, as the world's most desirable fish, can sell for as much as $880 per kilogram ($400 per pound). As a result, it is probably the most endangered of all large fish species.

The fishing industry has begun working its way down marine food webs by shifting from large species to smaller ones. This practice reduces the breeding stock needed for recovery of depleted species, which unravels marine food webs and disrupts marine ecosystems and their ecosystem services.

Most fishing boats hunt and capture one or a small number of commercially valuable species. However, their gigantic nets and incredibly long lines of hooks also catch nontarget species, called *bycatch.* Almost one-third of the world's annual fish catch, by weight, consists of these nontarget species, which are thrown overboard dead or dying. This can deplete the populations of bycatch species that play important roles in marine food webs. Marine mammals such as seals and dolphins can also become part of bycatch.

Fish species are also threatened with *biological extinction,* mostly from overfishing, water pollution, wetlands destruction, and excessive removal of water from rivers and lakes. According to the IUCN, 34% of the world's known marine fish species and 71% of the world's freshwater fish species face extinction within your lifetime. Indeed, *marine and freshwater fishes are threatened with extinction by human activities more than any other group of species.*

**RESEARCH FRONTIER**

Learning more about how aquatic systems work and how human activities affect aquatic biodiversity and aquatic ecosystem services. See **academic.cengage.com/biology/miller**.

## ■ CASE STUDY

## Industrial Fish Harvesting Methods

Industrial fishing fleets dominate the world's marine fishing industry. They use global satellite positioning equipment, sonar, huge nets and long fishing lines, spotter planes, and gigantic refrigerated factory ships that can process and freeze their catches. These fleets help meet the growing demand for seafood. But critics say that these highly efficient fleets are *vacuuming the seas,* decreasing marine biodiversity, and degrading important marine ecosystem services. Today 75% of the world's commercial fisheries are being fished at or beyond their estimated sustainable yields, according to the U.N. Food and Agricultural Organization.

Figure 11-7 shows the major methods used for the commercial harvesting of various marine fishes and shellfish. Until the mid-1980s, fishing fleets from developed countries dominated the ocean catch. Today, most of these fleets come from developing countries, especially in Asia.

Let us look at a few of these methods. *Trawler fishing* is used to catch fishes and shellfish—especially shrimp, cod, flounder, and scallops—that live on or near the ocean floor. It involves dragging a funnel-shaped net held open at the neck along the ocean bottom. It is weighted down with chains or metal plates and scrapes up almost everything that lies on the ocean floor and often destroys bottom habitats—somewhat like clear-cutting the ocean floor (Figure 11-3). Newer trawling nets are large enough to swallow 12 jumbo jet planes and even larger ones are on the way.

Another method, *purse-seine fishing,* 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 areas. After a spotter plane lo-

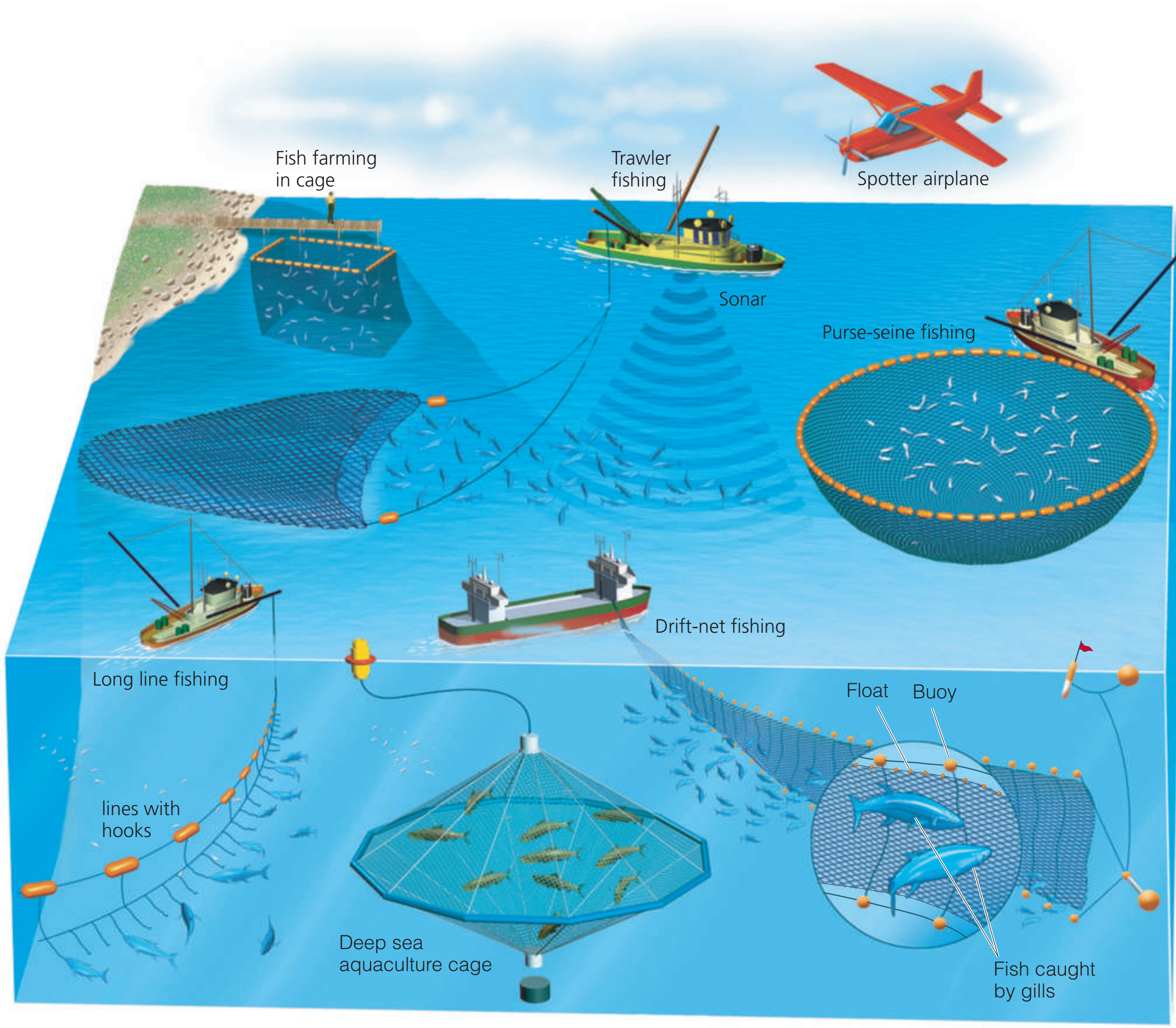



**Figure 11-7** Major commercial fishing methods used to harvest various marine species. These methods have become so effective that many fish species have become commercially extinct.

cates a school, the fishing vessel encloses it with a large net called a purse seine. Nets used to capture yellow fin tuna in the eastern tropical Pacific Ocean have killed large numbers of dolphins that swim on the surface above schools of tuna.

Fishing vessels also use *longlining,* which involves putting out lines up to 130 kilometers (80 miles) long, hung with thousands of baited hooks. The depth of the lines can be adjusted to catch open-ocean fish species such as swordfish, tuna, and sharks or bottom fishes such as halibut and cod. Longlines also hook and kill large numbers endangered sea turtles, dolphins, and seabirds each year. Making simple modifications to fishing gear and practices can decrease seabird deaths.

With *drift-net fishing,* fish are caught by huge drifting nets that can hang as deep as 15 meters (50 feet) below the surface and extend to 64 kilometers (40 miles) long. This method can lead to overfishing of the desired species and may trap and kill large quantities of unwanted fish, marine mammals, sea turtles, and seabirds.

Since 1992, a U.N. ban on the use of drift nets longer than 2.5 kilometers (1.6 miles) in international waters has sharply reduced use of this technique. But longer nets continue to be used because compliance is voluntary and it is difficult to monitor fishing fleets over vast ocean areas. Also, the decrease in drift net use has led to increased use of longlines, which often have similar harmful effects on marine wildlife.

# 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 using community-based integrated coastal management.**

## Laws and Treaties Have Protected Some Endangered and Threatened Marine Species

Protecting marine biodiversity is difficult for several reasons. First, the human ecological footprint (Figure 1-10, p. 15) and fishprint are expanding so rapidly into aquatic areas that it is difficult to monitor the impacts (**Concept 1-3**, p. 12). Second, much of the damage to the oceans and other bodies of water is not visible to most people. Third, 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. Finally, most of the world's ocean area lies outside the legal jurisdiction of any country. Thus, it is an open-access resource, subject to overexploitation.

CONCEPT LINK

Nevertheless, there are ways to protect and sustain marine biodiversity, one of which is the regulatory approach (**Concept 11-2**). National and international laws and treaties to 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, the U.S. Whale Conservation and Protection Act of 1976, and the 1995 International Convention on Biological Diversity.

The U.S. Endangered Species Act (Case Study, p. 207) and international agreements have been used to identify and protect endangered and threatened marine species such as whales (see the following Case Study), seals, sea lions, and sea turtles.

### ■ CASE STUDY
## Protecting Whales: A Success Story . . . So Far

*Cetaceans* are an order of mostly marine mammals ranging in size from the 0.9-meter (3-foot) porpoise to the giant 15- to 30-meter (50- to 100-foot) blue whale. They are divided into two major groups: *toothed whales* and *baleen whales* (Figure 11-8, p. 258).

*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 3-14, p. 63), from the seawater.

Whales are fairly easy to kill because of their large size and 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, with whalers killing an estimated 1.5 million whales between 1925 and 1975. This overharvesting drove 8 of the 11 major species to commercial extinction.

Overharvesting also drove some commercially prized species such as the giant blue whale (Figure 11-8) to the brink of biological extinction. The endangered blue whale is the world's largest animal. Fully grown, it is longer than three train boxcars and weighs more than 25 adult elephants. The adult has a heart the size of a Volkswagen Beetle, and some of its arteries are big enough for a child to swim through.

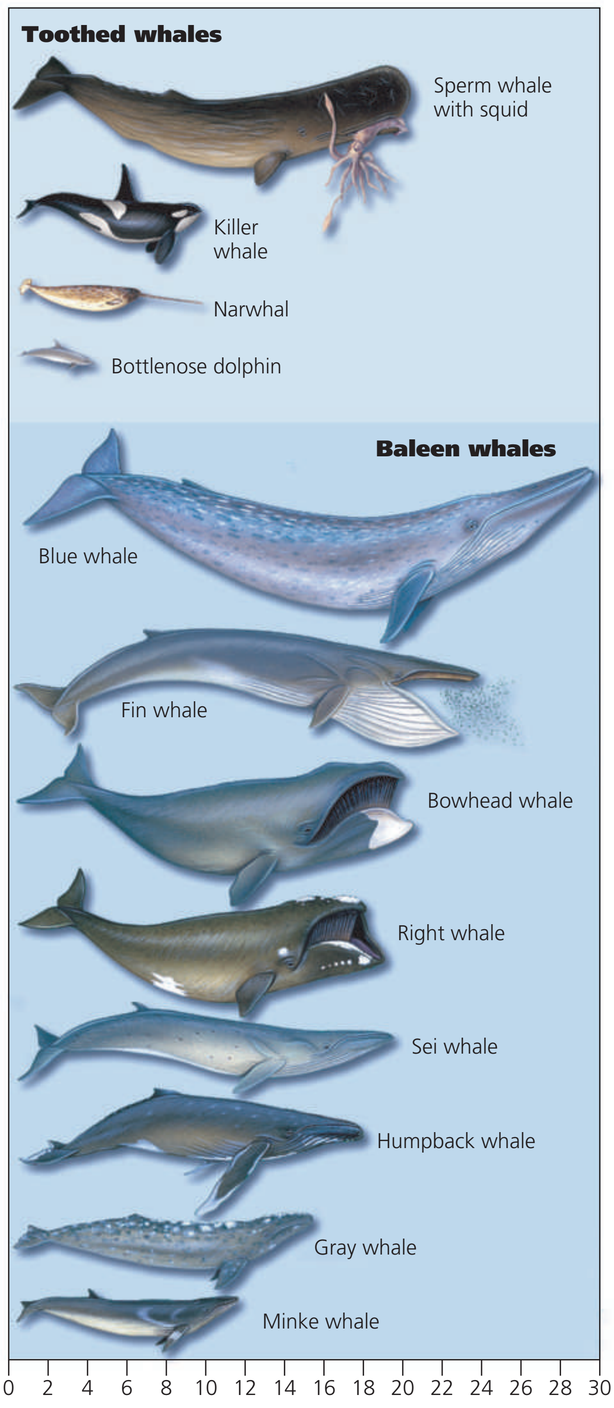



**Figure 11-8** *Examples of cetaceans,* which can be classified as either toothed whales or baleen whales.

Blue whales spend about 8 months a year in Antarctic waters. During the winter, they migrate to warmer waters where their young are born. Before commercial whaling began, an estimated 250,000 blue whales roamed the Antarctic Ocean. Today, the species has been hunted to near biological extinction for its oil, meat, and bone. There are probably fewer than 5,000 blue whales left. They take 25 years to mature sexually and have only one offspring every 2–5 years. This low reproductive rate will make it difficult for the species to recover.

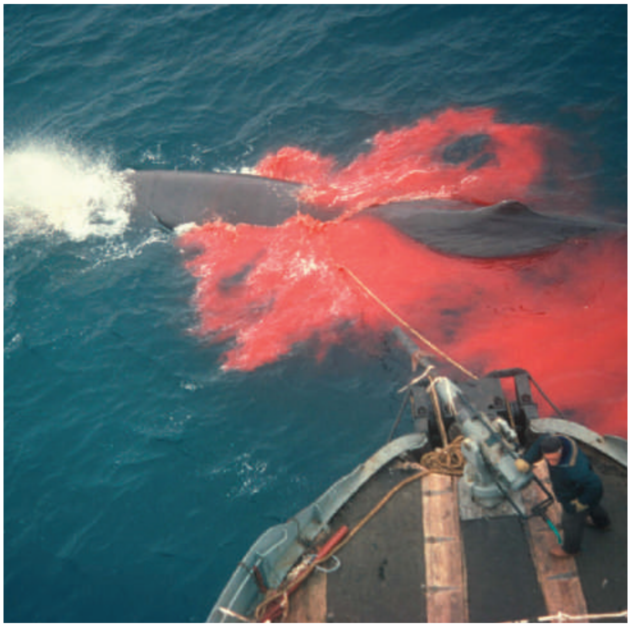
Blue whales have not been hunted commercially since 1964 and have been classified as an endangered species since 1975. Despite this protection, some marine biologists fear that too few blue whales remain for the species to recover and avoid premature extinction. Others believe that with continued protection they will make a slow comeback.

In 1946, the International Convention for the Regulation of Whaling established the International Whaling Commission (IWC). Its mission was to regulate the whaling industry by setting annual quotas to prevent overharvesting and commercial extinction. But IWC quotas often were based on inadequate data or were ignored by whaling countries. Without powers of enforcement, 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, the U.S. government, and governments of many nonwhaling countries, 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 1,300 in 2007. However, despite the ban, more than 26,000 whales were hunted and killed between 1986 and 2007.

Japan hunts and kills at least 1,000 minke and fin whales each year for what it calls "scientific purposes." Critics see this annual whale hunt as poorly disguised commercial whaling because the whale meat is sold to restaurants. Each whale is worth up to $30,000 wholesale. Norway openly defies the international ban on commercial whaling and hunts and kills up to 1,000 minke whales a year (Figure 11-9).

Japan, Norway, Iceland, Russia, and a growing number of small tropical island countries—which Japan brought into the IWC to support its position—hope to overthrow the IWC ban on commercial whaling and reverse the international ban on buying and selling whale products. They argue that commercial whaling should be allowed because it has been a traditional part of their economies and cultures.



Tony Martin/WWI Peter Arnold, Inc.

**Figure 11-9** Norwegian whalers harpooning a sperm whale. Norway and Japan kill up to 2,000 whales a year. They also believe that increased but sustainable commercial whaling should be allowed for sperm, minke, and pilot whales whose stocks have built back to large numbers.

Proponents of whaling also contend that the ban is emotionally motivated and not supported by current scientific estimates of whale populations. The moratorium on commercial whaling has led to a sharp rebound in these estimates for sperm, pilot, and minke whales.

Most conservationists disagree. Some argue that whales are peaceful, intelligent, sensitive, and highly social mammals that should be protected for ethical reasons. Others question IWC estimates of the allegedly recovered whale populations, noting the inaccuracy of such estimates in the past. And many conservationists fear that opening the door to any commercial whaling may eventually weaken current international disapproval and legal sanctions against commercial whaling and lead to widespread harvests of most whale species.

**HOW WOULD YOU VOTE?**

Should controlled commercial whaling be resumed for species with populations judged to be stable? Cast your vote online at **academic.cengage.com/biology/miller**.

Some coastal communities have an interest in maintaining the ban on whaling because they can provide jobs and income through increasingly popular whale watching. For example, The Nature Conservancy promoted whale watching in the town of Samaná in the Dominican Republic and has trained fishermen to work as whale-watching guides. The once run-down town has become a tourist hotspot, with spruced up houses, hotels, and inns, largely because of the popularity of whale watching. Local residents now have an economic interest in protecting the whales.

## Economic Incentives Can Be Used to Sustain Aquatic Biodiversity

Other ways to protect endangered and threatened aquatic species involve using economic incentives (**Concept 11-2**). For example, according to a 2004 World Wildlife Fund study, sea turtles are worth more to local communities alive than dead. The report estimates that sea turtle tourism brings in almost three times more money than does the sale of turtle products such as meat, leather, and eggs.

The problem is that individuals seeking to make a quick gain take the turtles before their surrounding communities can realize the longer-term economic benefits by protecting them. Educating citizens about this issue could inspire communities to protect the turtles (Case Study, below).

Some individuals find economic rewards in restoring and sustaining aquatic systems. One example is an application of *reconciliation ecology* by a restaurant owner (Individuals Matter, p. 261).

■ **CASE STUDY**

## Holding Out Hope for Marine Turtles

Of the seven species of marine turtles, six are either critically endangered or endangered. Among the latter is the leatherback sea turtle (Figure 11-10, p. 260), a species that has survived 100 million years, but now faces possible extinction. While their population is stable in the Atlantic Ocean, their numbers have declined by 95% in the Pacific.

Naturalist Carl Safina wrote about his studies of the leatherback in his book *Voyage of the Turtle*. He describes the leatherback as "the last living dinosaur." The largest of all sea turtles, and the only warm-blooded one, an adult turtle can weigh as much as 91 kilograms (200 pounds). It swims great distances, migrating across the Atlantic and Pacific Oceans, and it can dive as deep as 1,200 meters (3,900 feet). It is named for its leathery shell.

The leatherback female lays her eggs on sandy ocean beaches in the dark of night and then returns to the sea. The babies hatch simultaneously in large numbers and immediately scamper across the sand to try to survive to adulthood in ocean waters. As Safina describes it, "They start the size of a cookie, and come back the size of a dinosaur."

While leatherbacks survived the impact of the giant asteroid that probably wiped out the dinosaurs, they may not survive the growing human impact on their environment. Bottom trawlers are destroying the coral


**Figure 11-10** An endangered *leatherback sea turtle* is entangled in a fishing net and lines and could have starved to death had it not been rescued.

gardens that serve as their feeding grounds. The turtles are hunted for meat and leather, and their eggs are taken for food. They often drown after becoming entangled in fishing nets and lines (Figure 11-10) and lobster and crab traps. A 2004 study by R. I. Lewison and his colleagues estimated that in 2000 alone, longline fishing operations killed an estimated 50,000 leatherback and 200,000 loggerhead sea turtles. Shrimp trawling fisheries also kill large numbers of leatherback and other sea turtle species.

Pollution is another threat. Sea turtles can mistake discarded plastic bags for jellyfish and choke to death on them. Beachgoers sometimes trample their nests. And artificial lights can disorient hatchlings as they try to find their way to the ocean; going in the wrong direction increases their chances of ending up as food for predators.

Add to this the threat of climate change. Global warming will raise sea levels, which will flood nesting and feeding habitats, and change ocean currents, which could disrupt the turtles' migration routes.

Many people are working to protect the leatherbacks. On some Florida beaches, lights are turned off or blacked out during hatching season. Nesting areas are roped off, and people respect the turtles, according to Safina. Since 1991, the U.S. government has required offshore shrimp trawlers to use turtle excluder devices (TEDs), which help to keep sea turtles out of their nets and to allow caught turtles to escape. TEDs have been adopted in 15 countries that export shrimp to the United States. And, in 2004, the United States banned long-line swordfish fishing off the Pacific coast to help save dwindling sea turtle populations.

On Costa Rica's northwest coast in the community of Playa Junquillal, an important leatherback nesting area, residents learned that tourism can bring in almost three times as much money as selling turtle products can earn. Biologists working with the World Wildlife Fund there directed a community-based program to educate people about the importance of protecting leatherbacks and to create revenue sources for local residents based on tourism instead of on harvesting turtle eggs. Volunteers were enlisted to find and rescue nests before they could be poached and to build hatcheries to protect the eggs.

For the leatherback turtles, this program was a success. In 2004, on the local beaches, all known nests had been poached. The following year, all known nests were protected and none were poached. The leatherback had become an important economic resource for all, not for just a few, of the residents of Playa Junquillal.

**THINKING ABOUT**
**The Leatherback Sea Turtle**

Why should we care if the leatherback sea turtle becomes extinct? What are three things you would do to help protect this species from premature extinction?

## Marine Sanctuaries Protect Ecosystems and Species

By international law, a country's offshore fishing zone extends to 370 kilometers (200 statute 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.

Through the Law of the Sea 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 law to protect their fishing grounds, many governments have promoted overfishing, subsidized new fishing fleets, and failed to establish and enforce stricter regulation of fish catches in their coastal waters.

Some countries are attempting to protect marine biodiversity and sustain fisheries by establishing marine sanctuaries. Since 1986, the IUCN has helped to establish a global system of *marine protected areas* (MPAs)—areas of ocean partially protected from human activities. There are more than 4,000 MPAs worldwide, 200 of them in U.S. waters. Despite their name, most MPAs are only partially protected. Nearly all allow dredging, trawler fishing, and other ecologically harmful resource extraction activities. However, the U.S. state

## INDIVIDUALS MATTER

### Creating an Artificial Coral Reef in Israel

Near the city of Eliat, Israel, at the northern tip of the Red Sea, is a magnificent coral reef, which is a major tourist attraction. To help protect the reef from excessive development and destructive tourism, Israel set aside part of the reef as a nature reserve. But tourism, industrial pollution, and inadequate sewage treatment have destroyed most of the unprotected part of the reef.

Enter Reuven Yosef, a pioneer in coral reef restoration and reconciliation ecology, who has developed an underwater restaurant called the Red Sea Star Restaurant. Patrons take an elevator down two floors and walk into a restaurant surrounded with windows looking out on a beautiful coral reef.

This reef was created from pieces of broken coral. Typically, when coral breaks, the pieces become infected and die. But researchers have learned how to treat the coral fragments with antibiotics and to store them while they are healing in large tanks of fresh seawater. Yosef has such a facility, and when divers find broken pieces of coral in the reserve near Yosef's restaurant, they bring them to his coral hospital. After several months of healing, the fragments are taken to the underwater area outside the Red Sea Star Restaurant's windows where they are wired to panels of iron mesh cloth. The corals grow and cover the iron matrix. Then fish and other creatures show up.

Similarly, other damaged coral reefs are being restored. In 20 different countries, scientists have increased the revival and growth rate of coral on submerged metal structures by exposing them to low-voltage electricity.

Using his creativity and working with nature, Yosef has helped to create a marine ecosystem that people can view and enjoy while they dine at his restaurant. At the same time, he has helped to restore and preserve aquatic biodiversity.

of California in 2007 began establishing the nation's most extensive network of MPAs where fishing will be banned or strictly limited. Conservation biologists say this could be a model for other MPAs.

## Establishing a Global Network of Marine Reserves: An Ecosystem Approach to Marine Sustainability

Many scientists and policymakers call for adopting an entirely new approach to managing and sustaining marine biodiversity and the important ecological and economic services provided by the seas. The primary objective of this *ecosystem approach* is to protect and sustain whole marine ecosystems for current and future generations instead of focusing primarily on protecting individual species.

The cornerstone of this ecological approach is to establish a global network of fully protected *marines reserves,* some of which already exist. These areas are put off-limits to destructive human activities in order to enable their ecosystems to recover and flourish. This global network would include large reserves on the high seas, especially near highly productive nutrient upwelling areas (Figure 7-2, p. 142), and a mixture of smaller reserves in coastal zones that are adjacent to well-managed, sustainable commercial fishing areas. This would encourage local fishers and coastal communities to support them and participate in determining their locations. Some reserves could be made temporary or moveable to protect migrating species such as turtles. Governments could use satellite technologies to update fishing fleets about the locations of designated reserves.

Such reserves would be closed to extractive activities such as commercial fishing, dredging, and mining, as well as to waste disposal. Most reserves in the proposed global network would permit less harmful activities such as recreational boating, shipping, and in some cases, certain levels of small-scale, nondestructive fishing. However, most reserves would contain core zones where no human activity is allowed. Outside the reserves, commercial fisheries would be managed more sustainably by use of an ecosystem approach instead of the current approach, which focuses on individual species without considering their roles in the marine ecosystems where they live.

Marine reserves work and they work fast (see *The Habitable Planet,* Video 9, at **www.learner.org/resources/series209.html**). Scientific studies show that within fully protected marine reserves, fish populations double, fish size grows by almost a third, reproduction triples, and species diversity increases by almost one-fourth. Furthermore, this improvement occurs within 2–4 years after strict protection begins, and it lasts for decades (**Concept 11-2**). Research also shows that reserves benefit nearby fisheries, because fish move into and out of the reserves, and currents carry fish larvae produced inside reserves to adjacent fishing grounds, thereby bolstering the populations there.

In 2008, the Pacific island nation of Kiribati created the world's largest protected marine reserve. This California-sized area is found about halfway between the Pacific islands of Fiji and Hawaii. In 2006, the United States created the world's second largest protected reserve northwest of the U.S. state of Hawaii. The area is about the size of the U.S. state of Montana and supports more than 7,000 marine species, including the endangered Hawaiian monk seal (Figure 11-5) and the endangered green sea turtle (see photo on the title page of this book).

Still, less than 1% of the world's oceans are closed to fishing and other harmful human activities in marine reserves and only 0.1% is fully protected—compared to 5% of the world's land. Thus, we have reserved essentially 99.9% of the world's oceans to use as we see fit. Furthermore, many current marine reserves are too small to protect most of the species within them and do not provide adequate protection from illegal fishing or from pollution that flows from the land into coastal waters.

In 2006, a statement signed by 161 leading marine scientists called for urgent action to create a global network of fully protected marine reserves. Many marine scientists call for fully protecting at least 30% of the world's oceans as marine reserves, and some call for protecting up to 50%. They also urge connecting the global network of marine reserves, especially those in coastal waters, with protected corridors. This would also help species to move to different habitats in the process of adapting to the effects of ocean warming, acidification, and many forms of ocean pollution.

Establishing and managing a global network of marine reserves would cost an estimated $12–14 billion a year and create more than 1 million jobs, according to a 2004 study by the World Wildlife Fund International and Great Britain's Royal Society for Protection of Birds. This investment in protecting aquatic biodiversity and regenerating fisheries is roughly equal to the amount currently spent by governments on subsidies for the fishing industry, which conservationists say encourage overfishing.

D. Parer & E. Parer-Cook/Ardea

**Figure 11-11** An atoll of Australia's Great Barrier Reef.

**RESEARCH FRONTIER**

Determining characteristics and locations of fully protected marine reserves that will maximize their effectiveness. See **academic.cengage.com/biology/miller**.

**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?

## Protecting Marine Biodiversity Requires Commitments from Individuals and Communities

There is hope for significant progress in sustaining marine biodiversity, but it will require that we change our ways—and soon. For example, IUCN and The Nature Conservancy scientists reported in 2006 that the world's coral reefs and mangrove forests could survive currently projected global warming if we relieve other stressors such as overfishing and pollution. And while some 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 projected rate of global warming.

Increasing ocean acidity could have a major impact on corals and other marine organisms that build shells and skeletal structures out of calcium carbonate, which can dissolve at certain acidity levels. Increasing ocean acidity is likely to have serious impacts on the biodiversity and functioning of coral reefs. A 2005 report by the United Kingdom's Royal Society concluded that there was no way to reverse the widespread chemical and biological affects of increasing ocean acidification except by sharply reducing human inputs of $CO_2$ into the atmosphere, without delay.

To deal with these problems, communities must closely monitor and regulate fishing and coastal land development and prevent pollution from land-based activities. More important, each of us can make careful choices in purchasing only sustainably harvested seafood. Coastal residents must also think carefully about the chemicals they put on their lawns, and the kinds of waste they generate and where it ends up. And individuals can reduce their carbon footprints to slow climate change and its numerous harmful effects on marine and other ecosystems, as discussed in more detail in Chapter 19.

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**). Australia manages its huge Great Barrier Reef Marine Park this way, and more than 100 integrated coastal management programs are being developed throughout the world. Figure 11-11 shows an atoll of Australia's Great Barrier Reef, which employs integrated coastal management programs.

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 help to preserve biodiversity and environmental quality while also meeting various economic and social goals.

This requires all participants to seek reasonable short-term trade-offs that can lead to long-term ecological and economic benefits. For example, fishers might have to give up fishing in certain areas until stocks recover enough to restore biodiversity in those areas, which might then provide fishers with a more sustainable future for their businesses.

# 11-3 How Should We Manage and Sustain Marine Fisheries?

▶ **CONCEPT 11-3 Sustaining marine fisheries will require improved monitoring of fish populations, cooperative fisheries management among communities and nations, reduction of fishing subsidies, and careful consumer choices in seafood markets.**

## Estimating and Monitoring Fishery Populations Is the First Step

The first step in protecting and sustaining the world's marine fisheries is to make the best possible estimates of their fish populations (**Concept 11-3**). The traditional approach has used a *maximum sustained yield* (MSY) model to project the maximum number of fish that can be harvested annually from a fish stock 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 stocks. Also, harvesting a particular species at its estimated maximum sustainable level can affect the populations of other target and nontarget fish species and other marine organisms.

In recent years, some fishery biologists and managers have begun using the *optimum sustained yield* (OSY) concept. It attempts to take into account interactions among species and to provide more room for error. 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 any of these approaches because there is much to learn about the biology of fishes and because of changing ocean conditions. As a result, many fishery and environmental scientists are increasingly interested in using the *precautionary principle* (**Concept 9-4C,** p. 210) 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 can be sustained.

CONCEPT LINK

**RESEARCH FRONTIER**

Studying fish and their habitats to make better estimates of optimum sustained yields for fisheries. See **academic .cengage.com/biology/miller**.

## 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 that have sustained their fisheries, jobs, and communities for hundreds and sometimes thousands of years. An example is Norway's Lofoten fishery, one of the world's largest cod fisheries. For 100 years, it has been self-regulated, with no participation by the Norwegian government. Cooperation can work (**Concept 11-3**).

However, the influx of large modern 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 *comanagement,* in which coastal communities and the government work together to manage fisheries.

In comanagement, 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. Often communities focus on managing inshore fisheries, and the central government manages the offshore fisheries. When it works, community-based comanagement proves that overfishing is not inevitable.

## Government Subsidies Can Encourage Overfishing

A 2006 study by fishery experts U. R. Sumaila and Daniel Pauly estimated that governments around the world give a total of about $30–34 billion per year to fishers to help them keep their businesses running. That represents about a third of all revenues earned through commercial fishing. Of that amount, about $20 billion helps fishers to buy ships, fuel, and fishing equipment; the remaining money pays for research and management of fisheries.

Some marine scientists argue that, each year, $10–14 billion of these subsidies are spent to encourage overfishing and expansion of the fishing industry. At a 2007 meeting of the World Trade Organization, the United States proposed a ban on such subsidies. Actions to slash fishing subsidies were supported by a group of 125 marine scientists from 27 countries.

Many marine scientists also call for stronger global efforts to reduce illegal fishing on the high seas and in coastal waters. Actions could include closing ports and markets to such fishers, checking on the authenticity of ship flags, and prosecuting companies that carry out illegal fishing.

**THINKING ABOUT**
**Fishing Subsidies**

What are three possible harmful effects of eliminating government fishing subsidies? Do you think they outweigh the benefits of such an action? Explain.

## Some Countries Use the Marketplace to Control Overfishing

Some countries use a market-based system called *individual transfer rights* (ITRs) to control access to fisheries. In such a system, the government gives each fishing vessel owner a specified percentage of the total allowable catch (TAC) for a fishery in a given year. Owners are permitted to buy, sell, or lease their fishing rights as private property.

The ITR market-based system was introduced in New Zealand in 1986 and in Iceland in 1990. In these countries, there has been some reduction in overfishing and in the sizes of their fishing fleets, and the governments have ended fishing subsidies that encourage overfishing. But enforcement has been difficult, some fishers illegally exceed their quotas, and the wasteful bycatch has not been reduced.

In 1995, the United States introduced tradable quotas to regulate Alaska's halibut fishery, which had declined so much that the fishing season had been cut to only 2 days per year. Some fishers sold their quotas and retired, and the number of fishers declined. Halibut prices and fisher income rose, and with less pressure from the fishing industry, the halibut population recovered. By 2005, the season was 258 days long.

Critics have identified three problems with the ITR approach and have made suggestions for its improvement. *First,* in effect, it transfers ownership of fisheries in publicly owned waters to private commercial fishers but still makes the public responsible for the costs of enforcing and managing the system. Critics suggest collecting fees of up to 5% of the value of any catch from quota holders to pay for these costs.

*Second,* an ITR system can squeeze out small fishing companies that do not have the capital to buy ITRs from others, and it can promote illegal fishing by companies squeezed out of the market. For example, 20 years after the ITR system was implemented in New Zealand, five companies controlled 85% of the ITRs. Critics suggest limiting the number of rights that any one company can obtain.

*Third,* TACs are often set too high to prevent overfishing. Scientists argue the limit should be set at 50–90% of the estimated *optimal* sustainable yield. Most fishing industry interests oppose setting stricter rules for ITR systems.

**THINKING ABOUT**
**Individual Transfer Rights**

Do you support or oppose widespread use of ITR systems to help control access to fisheries? Explain.

## Consumer Choices Can Help to Sustain Fisheries and Aquatic Biodiversity

An important component of sustaining aquatic biodiversity and ecosystem services is bottom-up pressure from consumers demanding *sustainable seafood,* which will encourage more responsible fishing practices. In choosing seafood in markets and restaurants, consumers can make choices that will further help to sustain fisheries (**Concept 11-3**).

One way to enable this is through labeling of fresh and frozen seafood to inform consumers about how and where the fish and shellfish were caught. In the United Kingdom, the Waitrose supermarket food chain provides such information for all of the seafood sold at its fresh fish counters. See information on more sustainable seafood choices and download a convenient pocket guide at **www.seafoodwatch.org**.

Another important component is certification of sustainably caught seafood. The London-based Marine Stewardship Council (MSC) was created in 1997 to support sustainable fishing and to certify sustainably produced seafood. It operates in more than 20 nations. Only certified fisheries are allowed to use the MSC's "Fish Forever" eco-label. This certification shows that the fish were caught using environmentally sound and socially responsible practices. By 2007, some 21 wild capture fisheries worldwide were MSC-certified, 18 more were being assessed, and more than 600 seafood products were available with the MSC eco-label. Even so, by 2007 only about 6% of the world's wild capture fisheries were certified.

In 2006, Wal-Mart, the world's largest food retailer, pledged to sell only "MSC-certified" wild-caught fresh and frozen fish in North America within 3–5 years. If implemented, this will have a significant impact on the sustainability of the fresh and frozen seafood market.

Figure 11-12 summarizes actions that individuals, organizations, and governments can take to manage global fisheries more sustainably and to protect marine biodiversity and ecosystem services.

**SOLUTIONS**

**Managing Fisheries**

**Fishery Regulations**

Set catch limits well below the maximum sustainable yield

Improve monitoring and enforcement of regulations

**Economic Approaches**

Sharply reduce or eliminate fishing subsidies

Charge fees for harvesting fish and shellfish from publicly owned offshore waters

Certify sustainable fisheries

**Protect Areas**

Establish no-fishing areas

Establish more marine protected areas

Rely more on integrated coastal management

**Consumer Information**

Label sustainably harvested fish

Publicize overfished and threatened species




**Bycatch**

Use wide-meshed nets to allow escape of smaller fish

Use net escape devices for seabirds and sea turtles

Ban throwing edible and marketable fish back into the sea

**Aquaculture**

Restrict coastal locations for fish farms

Control pollution more strictly

Depend more on herbivorous fish species

**Nonnative Invasions**

Kill organisms in ship ballast water

Filter organisms from ship ballast water

Dump ballast water far at sea and replace with deep-sea water

**Figure 11-12** Ways to manage fisheries more sustainably and protect marine biodiversity and ecosystem services. **Question:** Which four of these solutions do you think are the most important? Why?

## 11-4 How Should We Protect and Sustain Wetlands?

▶ **CONCEPT 11-4 To maintain the ecological and economic services of wetlands, we must maximize preservation of remaining wetlands and restoration of degraded and destroyed wetlands.**

### Coastal and Inland Wetlands Are Disappearing around the World

Coastal and inland wetlands are important reservoirs of aquatic biodiversity that provide vital ecological and economic services. Despite their ecological value, the United States has lost more than half of its coastal and inland wetlands since 1900, and other countries have lost even more. New Zealand, for example, has lost 92% of its original coastal wetlands, and Italy has lost 95%.

People have drained, filled in, or covered over swamps, marshes, and other wetlands for centuries to create rice fields and to make land available for growing crops, expanding cities, and building roads. Wetlands have also been destroyed in the process of extracting minerals, oil, and natural gas, and in order to reduce diseases such as malaria by eliminating breeding grounds for disease-causing insects.

Wetlands serve as natural filters. Those around Lake Victoria (**Core Case Study**) have historically captured human and animal wastes and kept the lake water clean enough to be used as drinking water for millions of Africans. In 2006, the director of Uganda's wetlands program reported that extensive draining and building on Lake Victoria's coastal wetlands had led to serious water pollution that was killing fish and contaminating drinking water supplies for several countries. He noted that as the waste flow increases, still more wetlands are being destroyed. The Ugandan government is now working to protect its remaining wetlands.

To make matters worse, coastal wetlands in many parts of the world will probably be under water during your lifetime because of rising sea levels caused by global warming. This could seriously degrade aquatic biodiversity supported by coastal wetlands, including commercially important fishes and shellfish and millions of migratory ducks and other birds. It will also diminish the many other ecological and economic services provided by these wetlands.

## We Can Preserve and Restore Wetlands

Scientists, land managers, landowners, and environmental groups are involved in intensive efforts to preserve existing wetlands and restore degraded ones (**Concept 11-4**). Laws have been passed to protect existing wetlands. Zoning laws, for example, can be used to steer development away from wetlands.

A U.S. law requires a federal permit to fill in or to deposit dredged material into wetlands occupying more than 1.2 hectares (3 acres). According to the U.S. Fish and Wildlife Service, this law helped 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 remaining U.S. inland wetlands are under federal protection, and state and local wetland protection is inconsistent and generally weak.

The stated goal of current U.S. federal policy is zero net loss in the function and value of coastal and inland wetlands. A policy known as *mitigation banking* allows destruction of existing wetlands as long as an equal area of the same type of wetland is created or restored. However, a 2001 study by the National Academy of Sciences found that at least half of the attempts to create new wetlands failed to replace lost ones, and most of the created wetlands did not provide the ecological functions of natural wetlands. The study also found that wetland creation projects often fail to meet the standards set for them and are not adequately monitored.

Creating and restoring wetlands can be profitable. Private investment bankers make money by buying wetland areas and restoring or upgrading them, working with the U.S. Army Corps of Engineers and the EPA. They thus create wetland banks or credits that they can sell to developers. Currently, there are more than 400 wetland banks in the United States with a total of more than $3 billion a year in sales.

It is difficult to restore or create wetlands. Thus, most U.S. wetland banking systems require replacing each hectare of destroyed wetland with 2–3 or more hectares of restored or created wetlands as a built-in ecological insurance policy. **GREEN CAREER:** Wetlands restoration expert

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

## INDIVIDUALS MATTER

### Restoring a Wetland

As we learn more about the ecological and economic importance of coastal and inland wetlands, some people have begun to question common practices that damage or destroy these ecosystems. Can we turn back the clock to restore or rehabilitate lost wetlands?

California rancher Jim Callender decided to try. In 1982, he bought 20 hectares (50 acres) of a Sacramento Valley rice field that had been a marsh until the early 1970s. To grow rice, the previous owner had destroyed the marsh by bulldozing, draining, and leveling it, uprooting the native plants, and spraying with chemicals to kill snails.

Callender and his friends set out to restore the marsh. They hollowed out low areas, built up islands, replanted bulrushes and other plants that once were there, reintroduced smartweed and other plants used by migrating and marsh-dwelling birds, and planted fast-growing Peking willows. After years of care, hand planting, and annual seeding with a mixture of watergrass, smartweed, and rice, the land is once again a marsh used by migratory waterfowl.

Jim Callender and others have shown that at least some of the continent's degraded or destroyed wetlands can be reclaimed with scientific knowledge and hard work. Such restoration is useful, but to most ecologists, the real challenge is to protect remaining wetlands from harm in the first place.



**Figure 11-13** **Natural capital restoration:** wetland restoration at Fort Erie, Ontario, Canada before (right) and after (left).

**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.

Wetlands restoration is becoming a big business. While some wetlands restoration projects have failed, others have been very successful (Figure 11-13 and Individuals Matter, at left).

**RESEARCH FRONTIER**

Evaluating ecological services provided by wetlands, human impacts on wetlands, and how to preserve and restore wetlands. See **academic.cengage.com/biology/miller**.

A good example of an attempt to restore a once vast wetland is that of the Everglades in the U.S. state of Florida, as described in the following case study.

### ■ CASE STUDY

## Can We Restore the Florida Everglades?

South Florida's Everglades (USA) was once a 100-kilometer-wide (60-mile-wide), knee-deep sheet of water flowing slowly south from Lake Okeechobee to Florida Bay (Figure 11-14, p. 268). 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.

Since 1948, a massive water control project has provided south Florida's rapidly growing population with a reliable water supply and flood protection. But is has also contributed to widespread degradation of the original Everglades ecosystem.

Much of the original Everglades has been drained, diverted, paved over, ravaged by nutrient pollution from agriculture, and invaded by a number of plant species. As a result, the Everglades is now less than half its original size. Much of it has also dried out, leaving large areas vulnerable to summer wildfires. And much of its biodiversity has been lost because of reduced water flows, invasive species, and habitat loss and fragmentation from urbanization.

Between 1962 and 1971, the U.S. Army Corps of Engineers transformed the wandering 166-kilometer-long (103-mile-long) Kissimmee River (Figure 11-14, p. 268) into a straight 84-kilometer (56-mile) canal flowing into Lake Okeechobee. The canal provided flood control by speeding the flow of water but it drained large wetlands north of Lake Okeechobee, which farmers then turned into cow pastures.

To help preserve the wilderness in the lower end of the Everglades system, in 1947, the U.S. government established Everglades National Park, which contains about a fifth of the remaining Everglades. But this protection effort did not work—as conservationists had predicted—because the massive water distribution and land development project to the north cut off much of the water flow needed to sustain the park's wildlife.

As a result, 90% of the park's wading birds have vanished, and populations of other vertebrates, from deer to turtles, are down 75–95%. Florida Bay, south of the Everglades is a shallow estuary with many tiny islands, or *keys*. Large volumes of freshwater that once

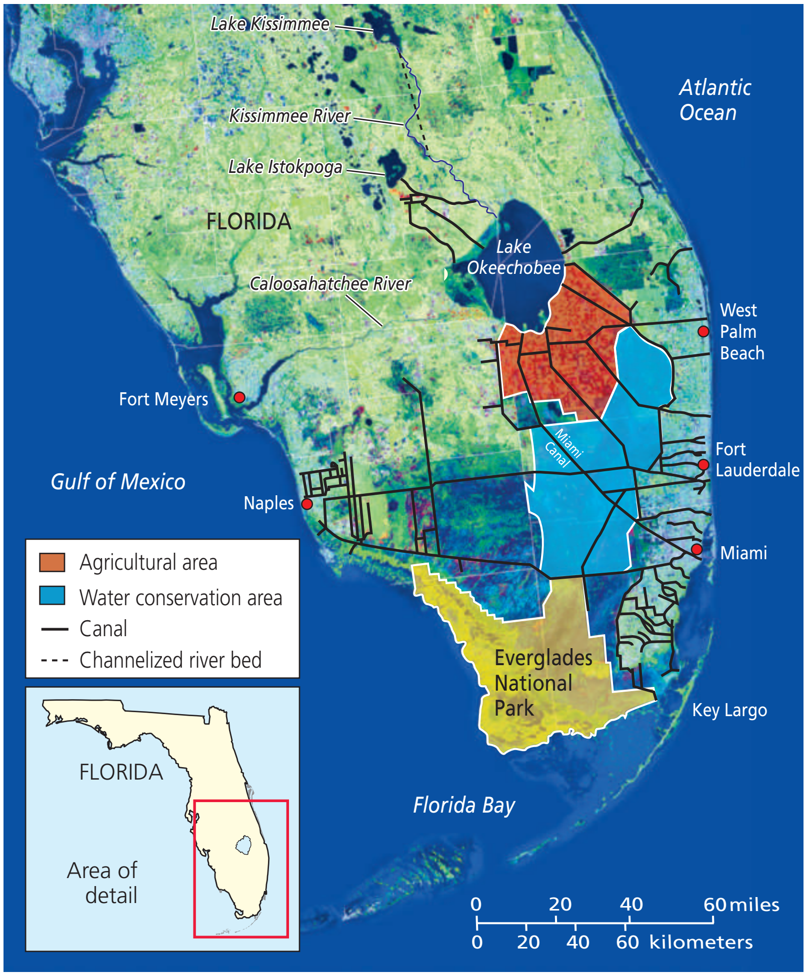



**Figure 11-14** The world's largest ecological restoration project is an attempt to undo and redo an engineering project that has been destroying Florida's Everglades (USA) and threatening water supplies for south Florida's rapidly growing population.

flowed through the park into Florida Bay have been diverted for crops and cities, causing the bay to become saltier and warmer. This, along with increased nutrient input from crop fields and cities, has stimulated the growth of large algal blooms that sometimes cover 40% of the bay. This has threatened the coral reefs and the diving, fishing, and tourism industries of the bay and the Florida Keys—another example of harmful unintended consequences.

By the 1970s, state and federal officials recognized that this huge plumbing project was reducing wildlife populations—a major source of tourism income for Florida—and cutting the water supply for the 6 million residents of south Florida. After more than 20 years of political haggling, in 1990, Florida's state government and the federal government agreed on the world's largest ecological restoration project, known as the Comprehensive Everglades Restoration Plan (CERP). 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. *First,* restore the curving flow of more than half of the Kissimmee River. *Second,* remove 400 kilometers (250 miles) of canals and levees blocking water flow south of Lake Okeechobee. *Third,* buy 240 square kilometers (93 square miles) of farmland and allow it to be flooded to create artificial marshes that will filter agricultural runoff before it reaches Everglades National Park. *Fourth,* create 18 large reservoirs and underground water storage areas to ensure an adequate water supply for south Florida's current and projected population and for the lower Everglades. *Fifth,* build new canals, reservoirs, and huge pumping systems to capture 80% of the water currently flowing out to sea and return it to 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 officials.

The carefully negotiated plan has begun to unravel. In 2003, sugarcane growers persuaded the Florida legislature to increase the amount of phosphorus they could discharge and to extend the deadline for reducing such discharges from 2006 to 2016. The project had originally been estimated to cost $7.8 billion and to take 30 years. By 2007, the price tag had risen to $10.5 billion and was expected to go much higher, mostly because of an almost tenfold increase in land prices in South Florida between 2000 and 2007. Overall, funding for the project, especially federal funding, has fallen short of the projected needs, and federal and state agencies are far behind on almost every component of the project. Now the project could take 50 years to complete, or it could be abandoned because of a lack of funding.

According to critics, the main goal of the Everglades restoration plan is to provide water for urban and agricultural development with ecological restoration as a secondary goal. Also, the plan does not specify how much of the water rerouted toward south and central Florida will go to the parched park instead of to increased industrial, agricultural, and urban development. And a National Academy of Sciences panel has found that the plan would probably not clear up Florida Bay's nutrient enrichment problems.

The need to make expensive and politically controversial efforts to undo some of the ecological damage done to the Everglades, caused by 120 years of agricultural and urban development, is another example of failure to heed two fundamental lessons from nature: prevention is the cheapest and best way to go; and when we intervene in nature, unintended and often harmful consequences always occur.

**THINKING ABOUT**
**Everglades Restoration**

Do you support carrying out the proposed plan for partially restoring the Florida Everglades, including having the federal government provide half of the funding? Explain.

# 11-5 How Can We Protect and Sustain Freshwater Lakes, Rivers, and Fisheries?

▶ **CONCEPT 11-5 Freshwater ecosystems are strongly affected by human activities on adjacent lands, and protecting these ecosystems must include protection of their watersheds.**

## Freshwater Ecosystems Are under Major Threats

The ecological and economic services provided by freshwater lakes, rivers, and fisheries (Figure 8-14, p. 174) are severely threatened by human activities (**Concept 8-5**).

CONCEPT LINK

Again, we can use the acronym HIPPCO to summarize these threats. As 40% of the world's rivers have been dammed or otherwise engineered, and as vast portions of the world's freshwater wetlands have been destroyed, aquatic species have been crowded out of at least half of their habitat areas, worldwide. Invasive species, pollution, and climate change threaten the ecosystems of lakes (Case Study, below), rivers, and wetlands. Freshwater fish stocks are overharvested. And increasing human population pressures and global warming make these threats worse.

Sustaining and restoring the biodiversity and ecological services provided by freshwater lakes and rivers is a complex and challenging task, as shown by the story of Lake Victoria (**Core Case Study**) as well as by the following Case Study.

CORE CASE STUDY

■ **CASE STUDY**

## Can the Great Lakes Survive Repeated Invasions by Alien Species?

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

Collectively, the Great Lakes are the world's largest body of fresh water. Since the 1920s, they have been invaded by at least 162 nonnative species, and the number keeps rising. Many of the alien invaders arrive on the hulls or in bilge water discharges of oceangoing ships that have been entering the Great Lakes through the St. Lawrence Seaway for almost 50 years.

One of the biggest threats, the *sea lamprey,* reached the western lakes through the Welland Canal in Canada as early as 1920. This parasite attaches itself to almost any kind of fish and kills the victim by sucking out its blood (Figure 5-4b, 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 in their spawning streams—at a cost of about $15 million a year.

In 1986, larvae of the *zebra mussel* (Figure 9-14, p. 199) arrived in ballast water discharged from a European ship near Detroit, Michigan (USA). This thumbnail-sized mollusk reproduces rapidly and has no known natural enemies in the Great Lakes. As a result, it has displaced other mussel species and depleted the food supply for some other Great Lakes species. The mussels have also clogged irrigation pipes, shut down water intake pipes for power plants and city water supplies, and fouled beaches. They have jammed ship rudders and grown in huge masses on boat hulls, piers, pipes, rocks, and almost any exposed aquatic surface (Figure 11-15). This mussel has also spread to freshwater communities in parts of southern Canada and 18 U.S. states. Currently, the mussels cost the two

NOAA Great Lakes Environmental Research Laboratory

**Figure 11-15** *Zebra mussels* attached to a water current meter in Lake Michigan. This invader entered the Great Lakes through ballast water dumped from a European ship. It has become a major nuisance and a threat to commerce as well as to biodiversity in the Great Lakes.

countries about $140 million a year—an average of $16,000 per hour.

Sometimes, nature aids us in controlling an invasive alien 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 be effective in controlling the invasive mussels in the long run.

Zebra mussels may not be good for some fish species or for us, but they can benefit a number of aquatic plants. By consuming algae and other microorganisms, the mussels increase water clarity, which permits deeper penetration of sunlight and more photosynthesis. This allows some native plants to thrive and could return the plant composition of Lake Erie (and presumably other lakes) closer to what it was 100 years ago. Because the plants provide food and increase dissolved oxygen, their comeback may benefit certain aquatic animals.

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. There is concern that it may spread by river transport and eventually colonize eastern U.S. ecosystems such as Chesapeake Bay and waterways in parts of Florida. In 2007, it was found to have crossed the United States, probably hitching a ride on a boat or trailer being hauled cross-country. It now resides in the Colorado River and reservoir system.

The *Asian carp* may be the next invader. These highly prolific fish, which can quickly grow as long as 1.2 meters (4 feet) and weigh up to 50 kilograms (110 pounds), have no natural predators in the Great Lakes. In less than a decade, this hearty fish with a voracious appetite has dominated sections of the Mississippi River and its tributaries and is spreading toward the Great Lakes. The only barriers are a few kilometers of waterway and a little-tested underwater electric barrier spanning a canal near Chicago, Illinois.

**THINKING ABOUT**

**Invasive Species in Lakes**

CORE CASE STUDY

What role did invasive species play in the degradation of Lake Victoria (**Core Case Study**)? What are three ways in which people could avoid introducing more harmful invasive species into lakes?

## Managing River Basins Is Complex and Controversial

Rivers and streams provide important ecological and economic services (Figure 11-16). But overfishing, pollution, dams, and water withdrawal for irrigation disrupt these services.

An example of such disruption—one that especially illustrates biodiversity loss—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 several major urban areas and for irrigating large areas of agricultural land.

**NATURAL CAPITAL**

**Ecological 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 11-16** Important ecological services provided by rivers. Currently, these 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 would help to sustain them. **Questions:** Which two of these services do you believe are the most important? Why? Which two of these services do you think we are most likely to decline? Why?

The Columbia River dam system has benefited many people, but it has sharply reduced populations of wild salmon. These migratory fish hatch in the upper reaches of streams and rivers, migrate to the ocean where they spend most of their adult lives, and then swim upstream to return to the places where they were hatched to spawn and die. Dams interrupt their life cycle.

Since the dams were built, the Columbia River's wild Pacific salmon population has dropped by 94% and nine 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, but none have been effective.

In another such case—on the lower Snake River in the U.S. state of Washington—conservationists, Native American tribes, and commercial salmon fishers want the government to remove four small hydroelectric dams to restore salmon spawning habitat. Farmers, barge operators, and aluminum workers argue that removing the dams would hurt local economies by reducing irrigation water, eliminating shipping in the affected areas, and reducing the supply of cheap electricity for industries and consumers.

**HOW WOULD YOU VOTE?**

Should U.S. government efforts to rebuild wild salmon populations in the Columbia River Basin be abandoned? Cast your vote online at **academic.cengage.com/biology/miller**.

## We Can Protect Freshwater Ecosystems by Protecting Watersheds

Sustaining freshwater aquatic systems begins with our realizing that whatever each of us does on land and in the water has some effect on those systems (**Concept 11-5**).

In other words, land and water are always connected in some way. 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.

As with marine systems, freshwater ecosystems can be protected through laws, economic incentives, and restoration efforts. For example, restoring and sustaining the ecological and economic services of rivers will probably require taking down some dams and restoring river flows, as may be the case with the Snake River, as mentioned above. And some scientists and politicians have argued for protecting all remaining free-flowing rivers.

With that in mind, in 1968, the U.S. Congress passed the National Wild and Scenic Rivers Act to establish protection of rivers with outstanding scenic, recreational, geological, wildlife, 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. But the Wild and Scenic Rivers System keeps only 2% of U.S. rivers free-flowing and protects only 0.2% of the country's total river length.

Sustainable management of freshwater fishes 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 way of 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 and farm ponds and stocking them with fish, fertilizing nutrient-poor lakes and ponds, and protecting and creating fish spawning sites. In addition, fishery managers can protect fish habitats from sediment buildup and other forms of pollution and from excessive growth of aquatic plants due to large inputs of plant nutrients.

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. However, all of these practices should be based on on-going studies of their effects on aquatic ecosystems and biodiversity. **GREEN CAREERS:** limnology, fishery management, and wildlife biology

**RESEARCH FRONTIER**

Studying the effects of resource management techniques on aquatic ecosystems. See **academic.cengage.com/biology/miller**.

# 11-6 What Should Be Our Priorities for Sustaining Biodiversity and Ecosystem Services?

▶ **CONCEPT 11-6 Sustaining the world's biodiversity and ecosystem services will require mapping terrestrial and aquatic biodiversity, maximizing protection of undeveloped terrestrial and aquatic areas, and carrying out ecological restoration projects worldwide.**

## We Need to Establish Priorities for Protecting Biodiversity and Ecosystem Services

In 2002, Edward O. Wilson, considered to be one of the world's foremost experts on biodiversity, proposed the following priorities for protecting most of the world's remaining ecosystems and species (**Concept 11-6**):

- Complete the mapping of the world's terrestrial and aquatic biodiversity so we know what we have and therefore can make conservation efforts more precise and cost-effective.
- Keep intact the world's remaining old-growth forests and cease all logging of such forests.
- Identify and preserve the world's terrestrial and aquatic biodiversity hotspots and areas where

deteriorating ecosystem services threaten people and many other forms of life.

- Protect and restore the world's lakes and river systems, which are the most threatened ecosystems of all.
- Carry out ecological restoration projects worldwide to heal some of the damage we have done and to increase the share of the earth's land and water allotted to the rest of nature.
- Find ways to make conservation financially rewarding for people who live in or near terrestrial and aquatic reserves so they can become partners in the protection and sustainable use of the reserves.

There is growing evidence that the current harmful effects of human activities on the earth's terrestrial and aquatic biodiversity and ecosystem services could be reversed over the next 2 decades. Doing this will require implementing an ecosystem approach to protecting and sustaining terrestrial and aquatic ecosystems. According to biologist 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.

This strategy for protecting the earth's precious biodiversity will not be implemented without bottom-up political pressure on elected officials from individual citizens and groups. People will also have to vote with their wallets by not buying products and services that destroy or degrade biodiversity. Finally, implementing this strategy will require concerted efforts and cooperation among scientists, engineers, and key people in government and the private sector.

## REVISITING Lake Victoria and Sustainability

CORE CASE STUDY

SUSTAINABILITY

This chapter began with a look at how human activities have upset the ecological processes of Africa's Lake Victoria (**Core Case Study**).

Lake Victoria and other cases examined in this chapter illustrate the significant human impacts that have contributed to habitat loss, the spread of invasive species, pollution, climate change, and depletion of commercially valuable fish populations, as well as degradation of aquatic biodiversity in general. We have seen that these threats are growing and are even greater than threats to terrestrial biodiversity.

We also explored ways to manage the world's oceans, fisheries, wetlands, lakes, and rivers more sustainably by applying the four **scientific principles of sustainability**. This means reducing inputs of sediments and excess nutrients, which cloud water, lessen the input of solar energy, and upset the natural cycling of nutrients in aquatic systems. It means placing a high priority on preserving the biodiversity and ecological functioning of aquatic systems and on maintaining natural species interactions that help to prevent excessive population growth of any one species, as happened in Lake Victoria.

***By treating the oceans with more respect***
***and by using them more wisely,***
***we can obtain more from these life-supporting waters***
***while also maintaining healthy***
***and diverse marine ecosystems.***

BRIAN HALWEIL

## REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 250. Describe how human activities have upset ecological processes in East Africa's Lake Victoria (**Core Case Study**). CORE CASE STUDY
2. What are three general patterns of marine biodiversity? Why is marine biodiversity higher **(a)** near coasts than in the open sea and **(b)** on the ocean's bottom than at its surface? Describe the threat to marine biodiversity from bottom trawling. Give two examples of threats to aquatic systems from invasive species. Describe the ecological experiment involving carp removal in Wisconsin's Lake Wingra. How does climate change threaten aquatic biodiversity?
3. What is a **fishprint?** Describe the collapse of the cod fishery in the northwest Atlantic and some of its side effects. Describe the effects of trawler fishing, purse-seine fishing, longlining, and drift-net fishing.
4. How have laws and treaties been used to help sustain aquatic species? Describe international efforts to protect

whales from overfishing and premature extinction. Describe threats to sea turtles and efforts to protect them.

5. Describe the use of marine protected areas and marine reserves to help sustain aquatic biodiversity and ecosystem services. What percentage of the world's oceans is fully protected from harmful human activities in marine reserves? Describe the roles of fishing communities and individual consumers in regulating fishing and coastal development. What is integrated coastal management?

6. Describe and discuss the limitations of three ways to estimate the sizes of fish populations. How can the precautionary principle help in managing fisheries and large marine systems? Describe the efforts of local fishing communities in helping to sustain fisheries. How can government subsidies encourage overfishing? Describe the advantages and disadvantages of using individual transfer rights to help manage fisheries.

7. Describe how consumers can help to sustain fisheries, aquatic biodiversity, and ecosystem services by making careful choices in purchasing seafood.

8. What percentage of the U.S. coastal and inland wetlands has been destroyed since 1900? What are three major ecological services provided by wetlands? How does the United States attempt to reduce wetland losses? Describe efforts to restore the Florida Everglades.

9. Describe the major threats to the world's rivers and other freshwater systems. What major ecological services do rivers provide? Describe invasions of the U.S. Great Lakes by nonnative species. Describe ways to help sustain rivers.

10. What are six priorities for protecting terrestrial and aquatic biodiversity? Relate the ecological problems of Lake Victoria (**Core Case Study**) to the four **scientific principles of sustainability**.

CORE CASE STUDY

SUSTAINABILITY

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

## CRITICAL THINKING

1. Explain how introducing the Nile perch into Lake Victoria (**Core Case Study**) violated all four **scientific principles of sustainability** (see back cover).

CORE CASE STUDY

SUSTAINABILITY

2. What difference does it make that the introduction of the Nile perch into Lake Victoria (**Core Case Study**) caused the extinction of more than 200 cichlid fish species? Explain.

CORE CASE STUDY

3. What do you think are the three greatest threats to aquatic biodiversity and ecosystem services? Why? Why are aquatic species overall more vulnerable to premature extinction resulting from human activities than terrestrial species are? Why is it more difficult to identify and protect endangered marine species than to protect endangered species on land?

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

5. Should fishers who harvest fish from a country's publicly owned waters be required to pay the government (taxpayers) 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 that about half of all attempts to create new wetlands fail to replace lost wetlands? Give three reasons why a constructed wetland might not provide the same level of ecological services as a natural wetland. Do you agree with some ecologists' argument that mitigation wetland banking should be used only as a last resort? Explain.

7. Do you think the plan for restoring Florida's Everglades will succeed? Give three reasons why or why not?

8. Dams on some rivers provide inexpensive hydroelectric power, but they also disrupt aquatic ecosystems. For example, production of hydroelectric power on the Columbia River has resulted in the degradation of the river's Pacific salmon population. Do you think the benefits of these dams justify the ecological damage they cause? Explain. If you see this as a problem, describe a possible solution.

9. Congratulations! You are in charge of protecting the world's aquatic biodiversity and ecosystem services. List the three most important points of your policy to accomplish this goal.

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

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

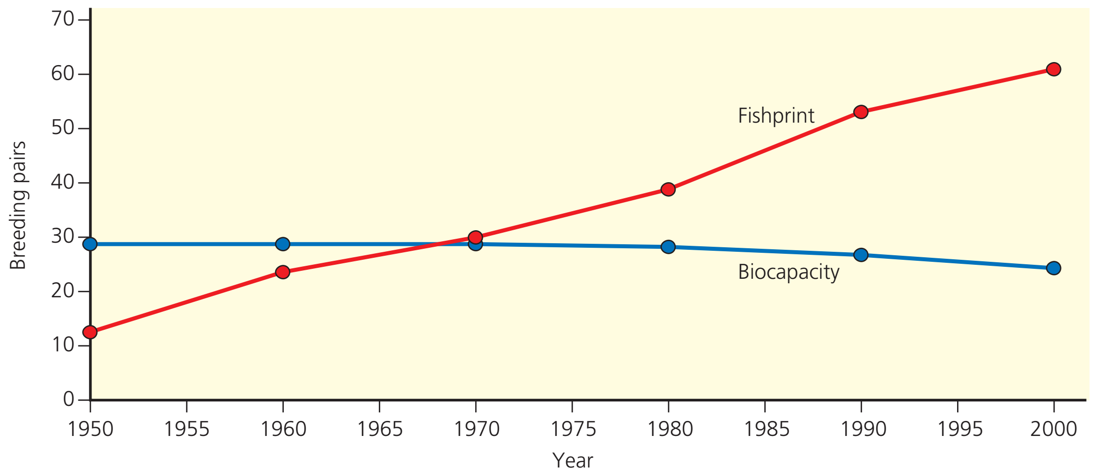
## ECOLOGICAL FOOTPRINT ANALYSIS

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 in terms of area, its fishprint indicates whether the country's fishing intensity is sustainable. The fishprint and biocapacity are calculated using the following formulae:

$$\text{Fishprint (in gha)} = \frac{\text{metric tons of fish harvested per year}}{\text{productivity in metric tons per hectare} \times \text{weighting factor}}$$

$$\text{Biocapacity (in gha)} = \frac{\text{sustained yield of fish in metric tons per year}}{\text{productivity in metric tons per hectare} \times \text{weighting factor}}$$

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




1. Based on the graph,
   a. What is the current status of the global fisheries with respect to sustainability?
   b. In what year did the global fishprint begin exceeding 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 fishing intensity sustainable?
   c. To what extent, as a percentage, is the country under- or overshooting its biological capacity?

## LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 11 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

# AP* Review Questions for Chapter 11

**Match the following fish harvesting methods with their descriptions:**

(A) Trawler fishing
(B) Purse-seine fishing
(C) Long line fishing
(D) Drift-net fishing
(E) Sonar

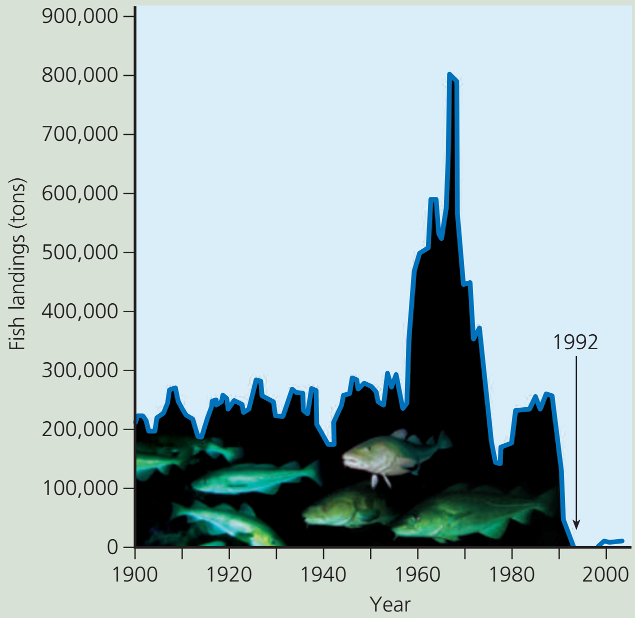
**1.** Enclosing a school of fish with a large net; used to capture yellow fin tuna

**2.** Can be 80 miles long with thousands of baited hooks; this often results in the bycatch of many ocean fish species

**3.** Dragging huge nets across the bottom of the ocean that are weighted down to harvest bottom fish and shellfish

**4.** Often called "ghost-fishing" because these huge nets are left for days to float in the ocean by themselves resulting in a large bycatch

**Use the graph of the collapse of the cod fishery in the northwest Atlantic to answer questions 5–7.**




**5.** Identify the 10-year period in which the greatest rate of decline in the fish harvest took place.
(A) 1940–1950
(B) 1950–1960
(C) 1960–1970
(D) 1970–1980
(E) 1990–2000

**6.** For that 10-year period, calculate the rate of decline in the fish harvest in tons per year.
(A) 700,000
(B) 70,000
(C) 7,000
(D) 600,000
(E) 60,000

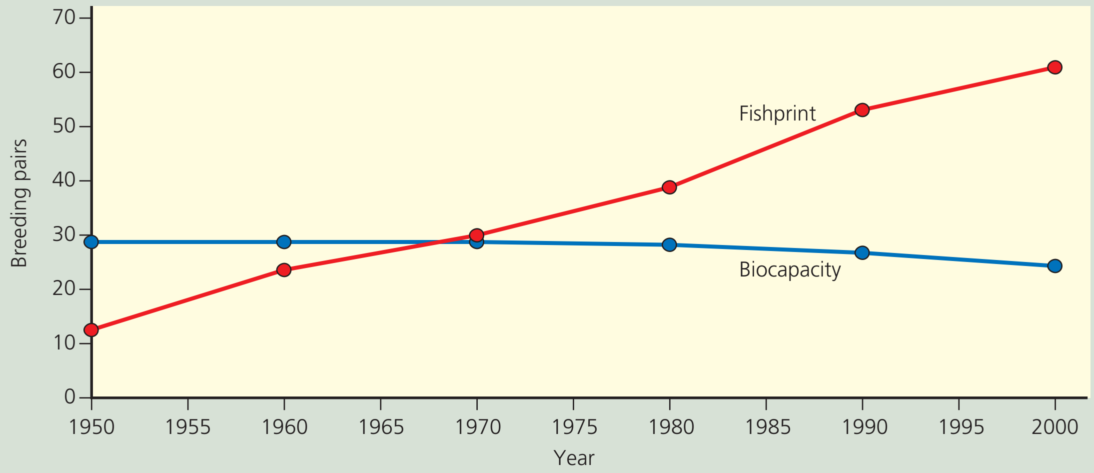
**7.** The graph illustrates a concept known as
(A) the tragedy of the commons.
(B) invasive species.
(C) bycatch.
(D) riparian destruction.
(E) biological extinction.

**8.** All of the following are ecological services provided by wetlands EXCEPT
(A) important reservoirs of aquatic biodiversity.
(B) natural filters.
(C) sources of drinking water.
(D) storm buffers during hurricanes and other tropical storms.
(E) important sources of arable land.

**9.** The U.S. federal policy that allows for the destruction of existing wetlands as long as an equal area of the same type of wetland is created is known as
(A) CERCLA.
(B) the Montreal Protocol.
(C) mitigation banking.
(D) FIRPA.
(E) the Law of the Sea.

**10.** One reason for the decline in recent years of the global fish catch is
(A) aquaculture.
(B) invasive species.
(C) ozone depletion.
(D) bioluminescence.
(E) overfishing.

**Use the graph below to answer the following questions**:




**11.** What is the relationship between fishprint and biocapacity?
(A) Inversely proportional
(B) Directly proportional
(C) Intermittent

**12.** In what year was the fishprint 33% above the biocapacity?
(A) 1950
(B) 1960
(C) 1970
(D) 1980
(E) 1990

**13.** Calculate the approximate percent change of fishprint from 1960 to 1980.
(A) 40%
(B) 50%
(C) 60%
(D) 70%
(E) 80%