CHAPTER 18

The Impact of Humans on the Marine Environment

The media offer disturbing news about the health of the oceans. Stories about global warming, pollution, dying coral reefs, and vanishing sea life are all too familiar. This is, however, only a small sample of **anthropogenic impacts,** or the effects of human activities, on the marine environment. More than 6.5 billion people now live on our planet (see Fig. 17.2), and more people now live within 100 km (60 mi) of the coast than lived on the *whole* planet in 1950! Everywhere, not just along industrial areas, the pressures of civilization are modifying the marine world. Water quality has decreased, fisheries are imperiled, recreational areas are at risk, and new health hazards are developing.

MODIFICATION AND DESTRUCTION OF HABITATS

Pollution is, unfortunately, not the only or necessarily most important way we affect the marine environment. This section briefly summarizes problems caused by human activities like dredging, the dumping of silt or mud, landfilling, or even of the use of explosives. Such activities modify or destroy **habitats,** the places where organisms live (Fig. 18.1). The effects of such physical disturbances are direct and immediate, as opposed to indirect effects like those of pollutants released somewhere else. The indirect effects of destruction of habitats, however, can be over much larger areas, as when the nursery grounds of fish are destroyed.

FIGURE 18.1 Salt marshes in Southern California and in many other locations around the globe have been obliterated with reclamation.

Most destruction of habitats takes place along the coast close to where people live, as in estuaries and mangrove forests (see "Human Impact on Estuarine Communities," p. 281). It results mostly from unplanned or poorly planned coastal development. The problem is more acute in developing nations, where population growth, poverty, and the absence of effective management are harmfully combined. The destruction of coastal habitats is certainly not restricted to poor countries, however. Growing cities, increased tourism, and development for industrial and recreational uses have radically altered the coastlines of the richer nations as well.

Coral Reefs

Coral reefs are threatened by human activities all over the tropics. More than a quarter of the world's coral reefs have already been lost or are at high risk. Though coral reefs support luxuriant life that provides much-needed protein and potentially life-saving drugs, they are subjected to much anthropogenic stress. This includes pollution by excess **nutrients** from sewage (see "The Kāne'ohe Bay Story," p. 310) and agricultural runoff, overgrowth by seaweeds (see "Grazing," p. 324), and overfishing. Like their also-threatened terrestrial counterparts, the tropical rain forests, coral reefs are among the oldest and richest environments on earth. Ironically, the rapid disappearance of tropical rain forests threatens coral reefs, too. The clearing, or deforestation, of the forests for agriculture, logging, and urban expansion increases the amount of soil washed out to sea by the plentiful tropical rain. In some places the resuspension of sediments by nearshore dredging also increases sediment loads.

Corals can tolerate moderate levels of sediment, but the higher levels produced by human activities may smother them. Furthermore, young corals do not settle on surfaces that are covered with sediment. Another harmful effect is that sediment in the water makes it more murky, reducing the amount of light that reaches the corals, which depend largely on food produced by **zooxanthellae.** Due to these various effects, sedimentation is a serious threat to many of the world's reefs.

FIGURE 18.2 Coral mining in the Maldive Islands, Indian Ocean. Reef-building corals are widely used as construction material in many parts of the tropics. Coral was used in the Maldives to build part of a new airport runway, even if the islands rely on their coral reefs to attract tourists, an important sector of the economy.

Coral reefs are extensively damaged or destroyed by explosives used to kill fishes. Even though illegal, dynamite fishing is practiced in many places. It may take several decades for damaged coral reefs to recover their former splendor. Explosives also are used to open navigation channels.

Fishing with poisons such as bleach and cyanide kills corals as well. Though this is generally banned, such poisons are widely used in Southeast Asia and parts of the western Pacific. Other threats are the mining of coral for construction material (Fig. 18.2) and the indiscriminate collection of corals for the

Nutrients Raw materials other than carbon dioxide and water that are needed by *primary producers* for *primary production.*

• Chapter 4, p. 68

Zooxanthellae Dinoflagellates (single-celled, photosynthetic algae) that live within animal tissues.

• Chapter 5, p. 96; Figure 14.1

aquarium trade and for sale as souvenirs and decorations. Shell collectors can be very destructive to coral reefs by turning over or breaking corals to get their specimens. Damage by anchors, fish traps, reef walking, and scuba diving has also taken their toll.

Another indication of stress to coral reefs is the worldwide outbreaks of mass coral **bleaching.** Shallow parts of about more than half of all coral reefs around the world showed bleaching in 1998. Biologists are increasingly concerned that global warming is causing higher water temperatures and thus more frequent, widespread, and severe bleaching events. Bleaching occurs when corals expel their symbiotic zooxanthellae, causing white patches to form on the colonies (Fig. 18.3). Recovery may take place because corals have different species of zooxanthellae and a new type may replace one that has been expelled. Bleached corals never lose all their symbionts. Even dying colonies have large numbers of zooxanthellae in their tissues, not enough to give color but enough to reestablish normal numbers when conditions are better. Bleached corals, however, do not grow and are vulnerable to disintegration.

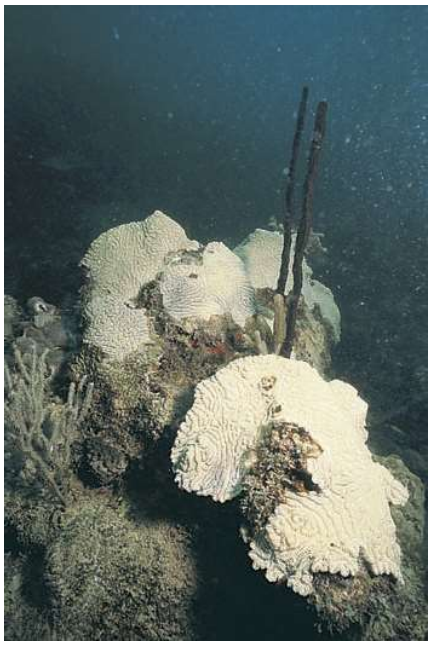


FIGURE 18.3 These colonies of a brain coral (*Meandrina meandrites*) in the Caribbean have become almost white after losing their symbiotic algae, or zooxanthellae, a phenomenon known as bleaching.

An increase in the appearance of killing diseases is additional evidence of coral stress. Infections typically show as a line of discolored dead tissue that exposes the underlying white skeleton as it advances over the colony. Various infections have been described, and their names ("black-band disease," "white-band disease") refer to the color of the advancing infection. These diseases (see Fig. 14.17) seem to be caused by bacteria and fungi that take hold on colonies damaged or stressed by excess nutrients.

Another major problem threatening corals is **ocean acidification,** which is caused by the increase in atmospheric CO_2. An increase in the acidity of the water makes the calcium carbonate ($CaCO_3$) skeleton of corals more soluble and it inhibits coral growth (see "Ocean Acidification: The Other CO_2 Problem," p. 235).

Coral reefs are being destroyed in many parts of the world as a result of direct human interference, which includes the use of explosives, indiscriminate collection, damage by anchors and divers, and potentially by ocean acidification.

Trawling

Trawls that are dragged along the bottom for fish and shrimp are a major threat to subtidal habitats. Trawling scours the seafloor and leaves scars on soft sediments, particularly muddy bottoms. It also causes the resuspension of sediment, which kills suspension feeders. On hard bottoms trawling breaks off many attached animals, some of which, like sponges and tubeworms, offer shelter to juveniles of fishes and other animals. Trawling also displaces or overturns boulders, harming or killing organisms living on their surface and exposing others to predators. Repeated trawling gives bottom communities little chance of recovery. The total number of species ultimately decreases markedly because the continuous disturbance favors short-living, fast-reproducing species like small worms, while long-living, slow-reproducing animals like sponges, clams, and sea stars tend to disappear. Deep-water trawling also threatens many vulnerable species that inhabit seamounts in deep water (see "Biodiversity in the Deep Sea," p. 375).

POLLUTION

Pollution—visible or invisible and on land, air, or water—is an unwanted but familiar part of our lives. **Pollution** can be described as the introduction by humans of substances or energy that decreases the quality of the environment. Many of these substances, or **pollutants,** are artificial substances that do not occur naturally. Some substances, however, have natural sources, such as natural oil seeps and volcanic eruptions, which are not considered to be sources of pollution. By contrast, the liberation by humans of naturally occurring substances, for example, when mining releases metals that are naturally stored in rocks, is considered to be pollution.

The role of humans in decreasing the quality of the marine environment has been enormous. The potentially detrimental effects of pollution can directly or indirectly affect all parts of the ocean, from beaches to the deepest depths. Pollution can also present a hazard to human health when marine organisms are eaten or when we go swimming, diving, or surfing.

Pollution is the introduction or release of substances or energy that decrease the quality of the marine environment. Many pollutants are toxic or harmful to marine life.

There is considerable diversity in the types, distribution, sources, and effects of marine pollutants, but most pollution comes from land-based sources, that is, from human activities on land. Major land-based pollution sources include urban development, agriculture and forestry, transport, industry, and power generation. The most important sea-based sources are shipping and offshore oil drilling, but these account for less than 20% of the total pollution that enters the ocean. Here we will briefly discuss only the most important types of marine pollutants and some of their effects on marine life.

Eutrophication

Fertilizers in agricultural runoff and sewage are major anthropogenic sources of nitrate, phosphate, and other nutrients to the marine environment. Atmospheric input from fossil fuel combustion is another major source of nitrogen, the largest, in fact, to the open ocean. Anthropogenic inputs of nitrogen to the oceans now exceed natural inputs. Thus, humans have come to dominate the global nitrogen cycle, and the situation will intensify because fertilizer use, fossil fuel combustion, and other human activities that increase nutrient inputs to the sea are ever expanding.

Though nutrients are needed by marine primary producers, excessive amounts encourage too much algal growth, a phenomenon known as **eutrophication** (see "Overwhelming the Nitrogen Cycle," p. 236). Eutrophication is primarily a problem of coastal waters, particularly in shallow, partially enclosed areas. Eutrophication can damage important habitats such as seagrass beds and coral reefs by causing a chronic increase in phytoplankton abundance, reducing the penetration of sunlight to the bottom, and accelerating the growth of seaweeds that overgrow the bottom (see "The Kāneʻohe Bay Story," p. 310). It may also trigger phytoplankton blooms, the short-term, explosive increases in the abundance of **phytoplankton.** Blooms of phytoplankton and particularly of bottom-dwelling cyanobacteria are sometimes toxic.

Organic matter in the form of the remains of the phytoplankton blooms and the feces of the zooplankton and fishes that feed on the plankton fall to the bottom, threatening already depleted fisheries. **Decay bacteria** then break down the organic matter. Bacteria may completely use up the oxygen on the bottom, causing **anoxic conditions.** Seasonal **hypoxic** (or "dead") **zones,** areas where the water lacks oxygen, that result from the effects of agricultural runoff have become common in a number of areas, including the Gulf of Mexico, (see "Gulf of Mexico's Hypoxic Zone," p. 406), Chesapeake Bay, and the Baltic Sea. About 150 hypoxic zones have been identified in oceans around the world (see "Special Report: Our Changing Planet," Fig. 14).

Coastal pollution may also be causing frequent red tides and other phytoplankton blooms (see "Red Tides and Harmful Algal Blooms," p. 334). These events seem to be occurring more frequently in many coastal waters. In Japan and China, for example, they endanger valuable mariculture operations. Blooms of phytoplankton and other algae have also become a recurrent problem in the Baltic and Adriatic seas. They cause millions of dollars worth of damage to fisheries, mariculture, and tourism.

Agricultural runoff, fossil fuel combustion, and other sources of increased nutrient inputs to the ocean are responsible for eutrophication, the excessive growth of phytoplankton and seaweeds.

Ironically, cutting down the amounts of nutrients that naturally enter the ocean can also be harmful. Dams and reservoirs that divert water for agricultural and other uses reduce the amount of nutrients that otherwise would have enriched the productivity of coastal regions, thus affecting fisheries. The building of dams and the diversion or canalization of rivers also reduce the amounts of sediments entering the ocean, severely increasing the erosion of the immediate coast.

Sewage

Disposing of ever-increasing amounts of **sewage** is a major problem in cities around the world. **Domestic sewage** carries all kinds of wastewater from homes and city buildings. It may also carry storm runoff water. **Industrial sewage** contains a variety of wastes from factories and the like. Most of society's sewage is discharged into the sea, or into rivers that flow to it. The vast amounts of sewage that enter the ocean threaten both the marine environment and human health.

Impacts of Sewage Sewage discharges into coastal waters are a serious health hazard, a threat more serious than once thought. Sewage contains many viruses, bacteria, and other parasites that cause disease. Infectious hepatitis, for example, is carried by viruses found in human feces. Some 2.5 million worldwide cases of infectious hepatitis annually result from people eating oysters, clams, and other shellfish that concentrate the viruses as they filter the water for food. Swimming in sewage-polluted water can also be hazardous; people can get sick from swallowing contaminated water or develop ear, throat, and eye infections just from contact with the water. The closing of beaches because of spills of raw sewage, common when sewers overflow after a rainstorm, has now become routine in many areas, especially where sewage and stormwater are discharged near shore. It has been recently estimated that in Southern California alone there are 1.5 million annual cases of gastrointestinal illnesses among recreational users as a result of sewage pollution, with a health cost of over $400 million. The economic impact due to lost tourism and the closure of shellfish farms can be considerable.

Sewage is discharged into the sea by many communities around the world. Sewage is a major health hazard to humans because it spreads disease.

Sewage Treatment and Sludge The harmful effects of sewage can be reduced by **sewage treatment,** and many countries require by law some form of treatment before sewage is discharged. The sewage may simply be allowed to sit in a basin for a time, so that much of the solid matter settles out. A more advanced, but also more expensive, option is to allow decay bacteria and other organisms

Phytoplankton The minute, drifting organisms that are a critical part of open-water communities because they perform practically all the photosynthesis in the open ocean.
• Chapter 15, p. 330

Decay Bacteria Bacteria and archaea that break down, or decompose, non-living organic matter into nutrients and other simple chemicals.
• Chapter 5, p. 87

Anoxic Conditions Absence of oxygen that results in the accumulation of *hydrogen sulfide* (H_2S) in the sediment, which turns the sediment black.
• Chapter 11, p. 260

EYE ON SCIENCE

Gulf of Mexico's Hypoxic Zone

The Gulf of Mexico is North America's most economically productive body of water, in part because of its rich commercial and recreational fisheries. Four of the top five U.S. fishery ports are in the Gulf of Mexico, and the Gulf generates about 20% of the total fisheries landings of the nation. The northern portion of the Gulf contains almost half of the nation's wetlands, and these wetlands, plus the region's seagrass beds, are essential habitats for the young of commercially important shrimps and fishes.

Threatening life in this northern section is the seasonal Gulf of Mexico's hypoxic zone (see "Overwhelming the Nitrogen Cycle," p. 236). The total area of the Gulf's hypoxic zone averaged 8,252 km^2 (3,186 mi^2) from 1985 to 1992, almost doubling to an average of 15,632 km^2 (6,036 mi^2) from 2000 to 2005 (see "Special Report: Our Changing Planet," Fig. 15). It is one of the largest hypoxic, or "dead," zones in the Northern Hemisphere.

Current research projects by the Center for Sponsored Coastal Ocean Research (CSCOR) are investigating the causes and the effects of hypoxia in the northern Gulf of Mexico. Being studied are the chemical, physical, and biological factors that influence the development of hypoxia, paying particular attention to the continental shelf off Louisiana. The main culprit of hypoxia in the Gulf is eutrophication caused by the huge amount of nutrients, especially nitrates, brought in by the Mississippi River. CSCOR research has shown that the source of most of the excess nutrients is fertilizers from agricultural runoff (see "Eutrophication," p. 405).

In addition to marine biologists, the investigation involves chemical and physical oceanographers. Factors such as nutrient inflow, circulation patterns, and freshwater input are being monitored. Research on the effects of hypoxia on the distribution, reproduction, and general health of commercially important shrimps and fishes is also being undertaken. It has been hypothesized that hypoxia may indirectly cause declines in the availability of food, increases in the exposure to predators, habitat loss, and even changes in behavior, particularly schooling among fishes. One project is looking at pelagic food webs by examining the distribution and abundance of open-water organisms from bacteria to fishes. Of special concern are changes in the distribution and mortality of endangered species such as sea turtles and cetaceans.

CSCOR projects aim to ultimately predict the extent and impact of hypoxia, particularly on fisheries. This will hopefully permit the implementation of strategies to change eutrophication and hypoxia conditions. A mathematical model has already suggested that a 30% reduction in the concentration of nitrogen entering the northern portion of the Gulf by 2015 may reduce the average size of the hypoxic zone to less than 5,000 km^2 (1,930 mi^2).

For more information, explore the links provided on the Marine Biology *Online Learning Center.*

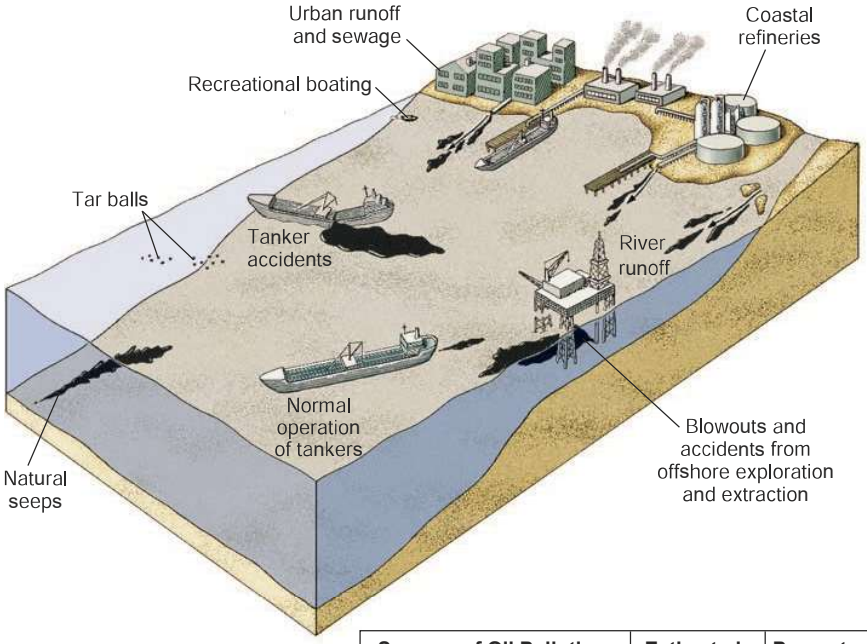
to break down the organic matter in the sewage. The addition of chemicals or other steps may be included to further purify the sewage. After treatment, the sewage is often disinfected by using chlorine to kill bacteria and some of the viruses. Ozone treatment and UV irradiation are other methods of disinfection. Sewage that contains industrial waste may also contain pesticides, heavy metals, and other toxic chemicals. Advanced forms of treatment can nevertheless produce water that is pure enough to be used for irrigation or even drinking water.

Sewage treatment greatly reduces the impacts of sewage on the marine environment and human health, but it is not without drawbacks. The cost of sewage treatment increases sharply as more advanced treatment methods are used, and many communities cannot afford it. Chlorine used for disinfection may remain in the discharged wastewater and is toxic to marine life. Sewage treatment also creates a new waste disposal problem: what to do with **sludge,** the wastes that are taken out of the sewage. This semiliquid material is much more concentrated than the original sewage and often contains high levels of heavy metals and other toxic substances. If the sludge is disposed of in the ocean, it smothers the natural communities on the bottom, creating black deserts around outfalls (Fig. 18.4).

It is impossible for most detritus feeders to handle the massive amounts of organic matter contained in sludge. The organic matter is instead decomposed by bacteria that thrive under these conditions. The decay bacteria use oxygen to such an extent that anoxic conditions develop. The total number of species decreases as many of the natural inhabitants disappear. They are replaced by hardier forms of life, such as certain species of polychaete worms. Bottom fishes collected around sludge disposal sites tend to show skin tumors, erosion of fins, and other abnormalities, apparently a result of the high concentration of toxic substances, viruses, and bacteria.

FIGURE 18.4
Treated sewage effluents from the Hyperion treatment plant being released at a depth of 60 m (180 ft) at the end of an 8-km (5-mi) outfall in Santa Monica Bay, Southern California. Large sea anemones (*Metridium*) surround the site. Santa Monica Bay is actually getting cleaner. The disposal of sludge from another treatment plant ended in 1987, and part of the wastewater at this outfall is now undergoing additional treatment. Treatment at the plant has been improved in order to meet standards set by the Environmental Protection Agency.

FIGURE 18.5 This lush artificial marsh is part of a network of marshes where domestic sewage from the town of Arcata in northern California is naturally purified before it is piped into the ocean. Sewage, which is mostly water, is given preliminary treatment, and chlorine is added to kill harmful bacteria. It is then pumped into the marshes, where mud bacteria break down the organic matter. The released nutrients fertilize the marsh plants. The marshes prevent the pollution of the ocean by sewage and attract many species of birds and other wildlife.



Sources of Oil Pollution in North America	Estimated Amount	Percentage
Natural seeps	160,000 tons	60%
Land-based pollution and recreational boating	84,000 tons	28%
Transportation of oil	9,100 tons	9%
Exploration and extraction	3,000 tons	3%

FIGURE 18.6 Annual sources of oil in the marine environment.

It is possible to implement alternatives to the discharge of sewage into the sea. Some communities take advantage of the ability of marshes to recycle nutrients by using the marshes for natural sewage treatment (Fig. 18.5). Additional and improved treatment, mandated in the United States by the Clean Water Act of 1972, has reduced the amount of suspended solids in the sewage being discharged in the country. But why not consider sewage a resource and turn it into something useful? Ideally we could recycle the large amounts of precious water and nutrients that go to waste. Sludge is sometimes recycled into landfill, construction blocks, and compost. It is also spread on farmlands as fertilizer, burned to generate electricity, and converted into fuel.

High volumes of sludge discharged into the sea greatly modify or destroy bottom communities.

Oil

Crude oil, or **petroleum,** is a complex mixture of **hydrocarbons,** long chains of carbon and hydrogen, and certain other chemicals. Crude oil is refined to yield not only fuels but raw materials for making plastics, synthetic fibers, rubber, fertilizers, and countless other products.

Sources Oil is one of the most widespread pollutants in the ocean. An estimated 682 million tons of oil and derivatives like fuel and lubricating oil enter the world oceans each year as a result of pollution. Oil from natural seepage, not a pollutant, contributes another 584 million tons worldwide. Natural seeps are the most important source of oil in North American waters, however, around 160,000 tons a year, while different sources of pollution contribute more than 96,000 tons annually (Fig. 18.6). Almost 85% of the polluting oil in North America comes from river runoff, coastal cities, fuel from small boats and jet skis, and fuel jettisoned by planes. The remaining 15% comes from tanker and pipeline spills and as a result of exploration and extraction from the seabed.

One metric ton of crude oil = 7.33 barrels (bbl), or 308 U.S. gal.

The massive oil spills that result from the sinking or collision of supertankers, however, are the most devastating to the marine environment. The 1978 grounding of a supertanker, the *Amoco Cadiz,* poured 230,000 tons of crude oil along the coasts of northwestern France. In 1989 more than 35,000 tons of crude oil were spilled by the *Exxon Valdez* along the coast of southern Alaska, the home of whales, sea otters, salmon, bald eagles, and other wildlife. Accidents have prompted tighter restrictions, such as having double hulls, on the construction and operation of tankers. Older tankers, however, do not necessarily have double hulls. Many still navigate busy shipping lines.

Most of the components of oil are insoluble in water and float on the surface. They appear as thin, iridescent slicks on the surface or as black deposits on the shore. You would expect large areas of the ocean to be covered with the oil that has accumulated over the years. Fortunately, some of its lighter components evaporate. Oil is ultimately broken down, or decomposed, by bacteria and thus is almost completely **biodegradable.** The breakdown rate is usually slow but varies among marine communities.

Some of the components of crude oil sink and accumulate in sediments, especially after the lighter ones evaporate. Other residues remain on the water surface and form tar balls, which are common along shipping lanes worldwide. They may persist for many years in the water and have been observed in remote areas far from shipping traffic. Some even have barnacles living on them! Extensive oil spills form huge layers that coat everything in their path as they are carried by wind and currents.

The oil and shipping industries have nevertheless made considerable progress in the protection of the marine environment. Illegal dumping is still a problem but it is becoming less severe. An indication of this is a decrease in the number of tar balls on many beaches.

Oil is a widespread pollutant that enters the sea as waste from land, from accidents during its extraction from the seabed, and as a result of its transportation across water.

Effects of Oil on Marine Life Even in small amounts, oil has a variety of effects in marine organisms. Organisms may accumulate oil components, many of which are toxic, from the water, sediments, and their food. There is evidence, for instance, that compounds found in oil interfere with the reproduction, development, growth, and behavior of many organisms. These compounds are released from oil for many decades. Oil also increases susceptibility to diseases in fishes and inhibits the growth of phytoplankton. Crude oils vary markedly in their chemical composition, and therefore in their toxicity and environmental persistence. Refined products such as fuel oils tend to be more toxic than crude oil.

Major oil spills can have disastrous effects in coastal environments. Seabirds and marine mammals like the sea otter are particularly susceptible. Many die of exposure when their feathers or hair is coated with oil (Fig. 18.7), which affects their ability to maintain the thin layer of warm air needed for insulation. Birds that rely on flying to catch food are unable to do so and die of starvation. It is difficult to determine the number of birds killed by oil spills because many sink without reaching the coast, where the corpses can be counted. About 3,200 dead birds, some belonging to rare species, were counted immediately after the *Amoco Cadiz* spill. The *Exxon Valdez* spill is believed to have killed between 100,000 and 300,000 seabirds and 3,500 to 5,000 sea otters. Estimates are that it will take up to 70 years for the wildlife in the area of the spill to recover fully. Sea otters and other wildlife are still affected by low fertility and high death rates.

FIGURE 18.7 An oil-coated loon (*Gavia*) during the *Exxon Valdez* spill in Alaska. Detergents, which can be used to disperse the oil and help prevent situations like this, were widely used during the *Torrey Canyon* spill on the English coast in 1967 but proved to be toxic and actually caused more damage than the oil itself.

The effect of oil spills on exposed rocky shores is less devastating than it may appear at first sight. Initially there is mortality among many attached inhabitants, but wave action and tides help clean away the oil. Rocky shore communities do recover, though recovery is dependent on factors such as the amount of oil, wave action, and temperature. Degradation by bacteria takes place, but usually slowly, especially in cold water. Spills may be degraded more quickly by bacteria if an oil-soluble fertilizer is added to the water or sprayed on rocks and sediment. Experience has shown that recovery begins within months and that an apparently near-normal condition may occur as early

as one or two years after the spill. Higher oil concentrations in sediments and isolated pockets, however, have been found to remain for 15 years or longer.

Large spills can have more catastrophic effects when they drift to salt marshes and mangrove forests. These communities are characteristic of sheltered coasts and estuaries where oil cannot be dispersed by wave action. Massive mortality of the dominant plants takes place, and recovery is very slow. Oil is absorbed by the fine sediment characteristic of these communities and may persist for more than 30 years in salt marshes. Coral reefs and seagrass beds also are greatly affected by oil spills. Coral colonies show swollen tissues, excessive production of mucus, and areas without tissue. Reproduction and feeding in surviving coral polyps are affected by oil. There is little evidence, however, of dramatic, long-term effects.

Oil is harmful to most marine organisms. It is especially destructive to communities typical of shallow, sheltered waters.

Containing an oil spill and cleaning up the mess is a major headache. Fencing off the spill with floating, fire-resistant booms can prevent the spill from moving into shore. "Skimmers," boats equipped with U-shaped booms, are used to skim off and recover some of the oil. These methods, however, cannot be used in heavy seas. Chemical **dispersants** are added to the spill to break the surface oil into small droplets that can then disperse in the water. Unfortunately, dispersants also are harmful to marine life, and the dispersed oil still remains toxic underwater. The use of powerful streams of hot water to wash oil from beaches after the *Exxon Valdez* spill was also harmful to many forms of life, perhaps as harmful as the oil itself.

A more recent oil spill was that of the *Prestige,* a tanker that split in two and sank off the northwestern coast of Spain in 2002. It spilled 63,000 tons of oil, creating a slick 30 km (18 mi) long that reached the Spanish coast, devastating valuable shellfish fisheries and leaving more than 100,000 people without jobs. The spill caused a general outcry that ultimately affected national elections in Spain. The *Prestige* sank with an additional estimated 40,000 tons of oil, thus creating the uncertainty of future spills.

The cost of oil spills to local economies can be enormous. Fish and filter-feeding shellfish like oysters and clams that are tainted with oil are unmarketable. The size of fish catches, particularly of bottom-dwelling species, may decrease because of the initial mortality of adults and juveniles or a drop in the abundance of their food. Furthermore, oil-soaked beaches are disastrous to resort areas dependent on tourism. Claims by those affected plus the cleanup bill can run well past the billion-dollar mark. Exxon was ordered to pay a total of $5 billion in fines for damage caused by the *Exxon Valdez.* The fine was halved to $2.5 billion in 2006, but Exxon appealed.

Persistent Toxic Substances

Many important pollutants that reach the sea from land are substances that are said to be **persistent** because they remain in the environment for years, even many decades. Persistent substances are not readily broken down either by decay microorganisms (and for this reason the substances are known as **non-biodegradable**) or by physical or chemical means in the environment.

Pesticides One group of synthetic chemical pollutants is the **chlorinated hydrocarbons.** They include many **pesticides,** chemicals used to kill insects and to control weeds, including DDT, dieldrin, heptachlor, and chlordane. Millions of tons of these and many other chlorinated hydrocarbons have been used since the 1940s, when DDT made its debut. These pesticides have been used to protect plant crops from insect pests and to control insects that carry diseases. Pesticides have saved millions of people from disease and starvation, but the unchecked use of chlorinated hydrocarbons has exposed their sinister side, the fact that they are harmful to many non-targeted forms of life.

These pesticides have not been used directly in the ocean. They are, however, carried into the ocean by rivers, runoff, and sewage and are transported long distances, even to the open ocean, in the atmosphere (Fig. 18.8). In the ocean they are absorbed by phytoplankton and particles suspended in the water and thus find their way into the food chain.

Chlorinated hydrocarbon pesticides dissolve in fats and are not excreted, so organisms tend to retain them almost indefinitely. Animals absorb and accumulate the pesticides in the organisms they eat, so their internal concentration of chlorinated hydrocarbons is higher than in their food supply. At each level of the **food chain,** then, the chlorinated hydrocarbons are more concentrated. This phenomenon is known as **biological magnification.** Among marine animals, pesticide concentrations are higher in carnivorous fishes, and even more so in the fish-eating birds and mammals at the top of the **trophic pyramid** (Fig. 18.8).

Chlorinated hydrocarbons, which include many widely used pesticides, are non-biodegradable and persistent. Many accumulate in the food chain through biological magnification.

The alarming effects of worldwide use of chlorinated hydrocarbons began to be noticed during the 1960s. Fishes caught for human consumption in the United States had to be destroyed because they contained too much pesticide. Pesticides began to accumulate in top carnivores in concentrations that were thousands and even millions of times above those found in seawater.

The effects on birds, on land and at sea, were particularly dramatic. The birds were not actually poisoned, but the high

Food Chain The steps of transfer of energy from *producers,* the algae and plants, through *consumers,* the animals.
• Chapter 10, p. 221; Figure 10.13

Trophic Pyramid The pyramid-like relationship of energy, number of individuals, or biomass of the organisms found in a food chain.
• Chapter 10, p. 223; Figure 10.16

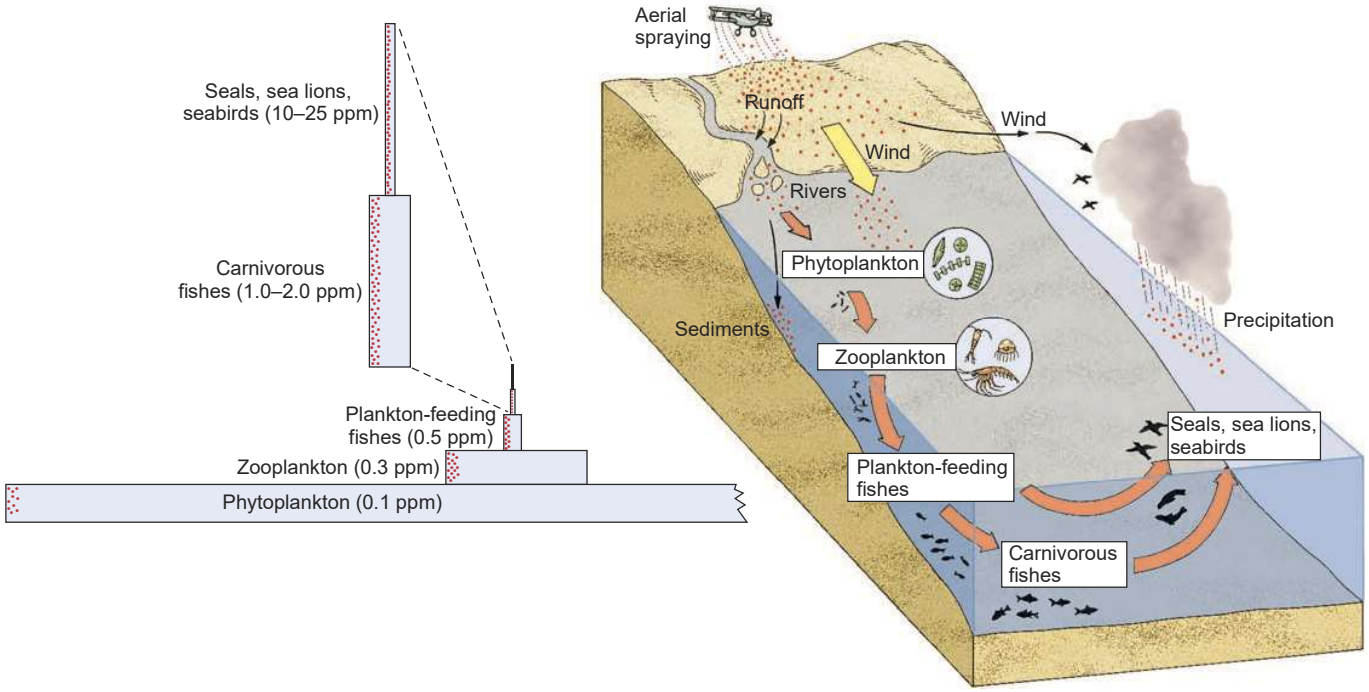


FIGURE 18.8 The concentration of chlorinated hydrocarbons increases with the relative position organisms have in the food chain, thus showing biological magnification. In the trophic pyramid that summarizes this generalized food chain, the concentration of pesticides is expressed in ppm, or parts per million.

concentrations of chlorinated hydrocarbons in their body fat interfered with reproduction, specifically with the deposition of calcium in their eggshells. The eggshells became so thin that they broke during incubation before chicks became fully developed.

The once-abundant brown pelican (Fig. 18.9), for example, became a rare sight in most of the United States due to widespread reproductive failure during the late 1960s and early 1970s. Female pelicans sat on broken eggs, or adults simply did not attempt to nest. The Channel Islands off Southern California, the last remaining nesting colony on the Pacific coast north of Mexico, recorded only one chick in 1970 and seven in 1971. High amounts of DDT and related chemicals were found in the tissues of birds taken from these and other nesting colonies and in other marine animals in the area, from filter feeders like sand, or mole, crabs to top carnivores like sea lions.

By 1972 most uses of DDT and several other chlorinated hydrocarbons were banned in the United States and many other industrialized nations. DDT residues in marine animals and sediments then began to decrease. The brown pelican, once nearly extinct in the United States, has recovered, and its reproduction has returned to normal. DDT and related residues, however, can still be found in bottom-dwelling fishes. One of these residues, DDE, was found to be degraded by bacteria under laboratory conditions. A 2000 international agreement restricting the production and use of certain toxic substances nevertheless allowed continued use of DDT because it provides inexpensive control of insects in developing nations, primarily to control the mosquitos that transmit malaria.

FIGURE 18.9 The brown pelican (*Pelecanus occidentalis*) is again a common sight along the coasts of the United States.

PCBs and Other Toxic Organic Chemicals Another problematic group of toxic chlorinated hydrocarbons are the **PCBs,** the **polychlorinated biphenyls.** PCBs are non-biodegradable and persistent and show biological magnification. They were widely used in electrical transformers and capacitors, in the manufacturing of plastics and paints, and in many other products. PCBs proved to be highly toxic, causing cancer and birth defects, and their production and use were gradually regulated or banned by many nations, including the United States in 1979.

This ban, however, came after PCBs had spread throughout the oceans. PCBs and other chlorinated hydrocarbons have been detected in the blubber of whales and other marine mammals. Salmon migrating

FIGURE 18.10 Hazardous chemicals such as PCBs and pesticides and other cancer-causing agents like vinyl chloride and chlorinated dioxins can be disposed of by incinerating them on the high seas rather than using dumps on land. Incinerator ships like this one burn hazardous organic chemicals at high temperatures, which results for the most part in chemicals like carbon dioxide and water. Transporting the toxic waste by sea, however, adds to the danger of spills. There are also concerns about the toxicity of hydrogen chloride and other chemicals that can be formed in the process. Very few nations dispose of all of the hazardous waste they produce on their own turf. Most simply export the waste and have other, usually poorer, nations get rid of it for a fee. A 1989 international treaty restricts, but does not ban, the international movement of toxic wastes.

to lakes and rivers release PCBs contained in their tissues when they die by the thousands after spawning. Furthermore, PCBs continue to be used in some parts of the world, and electrical equipment containing them is still around us. Such equipment is required to remain sealed and the PCBs carefully disposed of when it wears out. Invariably, though, PCBs are present in large amounts of hazardous wastes that accumulate and have to be disposed of somehow, somewhere (Fig. 18.10). PCBs are widespread in landfills and waste dumps. Like other chlorinated hydrocarbons, decades of use and disposal have also left significant amounts of these persistent pollutants in the marine environment, especially around sewage outfalls and in the sediment of harbors of industrial cities. Some marine bacteria, however, are known to degrade PCBs in sediments. They have been found mostly in areas with high concentrations of PCBs such as the Hudson River estuary.

Chlorinated **dioxins** and **furans,** two other groups of chlorinated hydrocarbons, also enter the marine environment from land. Pulp mills and waste incinerators are important sources of the chemicals, which also occur naturally, for example, as a result of forest fires. Some dioxins are among the most toxic of all chemical pollutants. They are carcinogenic and cause birth defects and damage to the immune system in many vertebrates and humans. Furthermore, they show biological magnification.

PCBs, a group of chemicals used as fire retardants (PBDEs), certain pesticides, and other toxic chemicals evaporate into the atmosphere, where the wind can carry them considerable distances before they condense in the cool upper atmosphere. When they condense, they are carried in rain or snow back to the ground, where the process starts all over again. Because of wind patterns and the fact that more condensation of the chemicals takes place near the poles, where it is cold, the chemicals are concentrated in polar regions. This global system of evaporation and condensation of substances, many of which are toxic, is known as **global distillation.** Global distillation has been implicated in whale kills, and high levels of PCBs and other toxic chemicals have been found in seals, polar bears, whales, and even the Inuit and other aboriginal peoples of the once pristine Arctic region and thousands of miles from where the pollutants were used.

PCBs, dioxins, and furans are pollutants notable for their toxicity. They are persistent and show biological magnification.

Even at low concentrations years after being banned, PCBs and other chlorinated hydrocarbons have been implicated in abnormal sexual behavior and reproductive ability in seabirds, marine mammals, and fishes. These pollutants form chemicals that are similar to sex hormones and seem to disrupt reproduction.

Heavy Metals An additional category of chemical contaminants of the world's oceans is metals, particularly those classified as **heavy metals.** Very minute amounts of some metals are needed by most if not all organisms, but an excess can be toxic.

One particularly troublesome heavy metal is **mercury,** which reaches the ocean through several natural processes: the weathering of rocks, volcanic activity, rivers, and dust particles from the atmosphere. Even so, human activities play an increasingly important role, especially along the coast. Mercury was once an active ingredient in chemicals used to kill bacteria and molds and in antifouling paints. It also is used in the production of chlorine and plastics and other chemical processes and in batteries, fluorescent lamps, drugs, and even tooth fillings. Discharges from industries and cities and the burning of coal, which contains traces of mercury, have increased the concentration of mercury in the marine environment.

Pure, liquid mercury, like that in thermometers, is harmless unless its vapors are inhaled. It is a different story when mercury combines with organic chemicals, as when transformed by some bacteria and other microbes in the water or sediment. These organic compounds, such as **methyl mercury,** are persistent and accumulate in the food chain. Levels of mercury

too high for human consumption have been found in large fishes such as tuna and swordfish. The older the fish, the higher the mercury content. Methyl mercury also can be found in coastal sediments, particularly around areas where wastes are dumped. Mercury compounds also undergo global distillation. They are very difficult to eliminate and are highly toxic to practically all forms of life. In humans they can cause brain, kidney, and liver damage and birth defects.

The dangers of the presence of mercury in seafood were demonstrated by the appearance in the 1950s and 1960s of a crippling neurological disorder among the inhabitants of a town in southern Japan (Fig. 18.11). The victims were poisoned by eating fish and shellfish that contained concentrated mercury discharged at sea by a chemical plant. More recently, high levels of mercury in fish prompted the United States government in 2004 to warn pregnant women and young children to limit their intake of canned tuna, swordfish, and other fishes.

Lead is another widespread heavy metal pollutant. As with mercury, organic lead compounds are persistent and concentrate in the tissues of organisms. Lead is toxic to humans, causing nervous disorders and death. The principal source of lead pollution in the marine environment is the exhaust of vehicles run with leaded fuels. The lead reaches the water by way of rain and windblown dust. Lead has also found its way into all sorts of products, such as paints and ceramics, that eventually make their way to the ocean.

The removal of lead from gasoline has been responsible for a decrease in lead levels in surface water, especially in the North Atlantic. This represents a success story that demonstrates that environmental problems can be addressed.

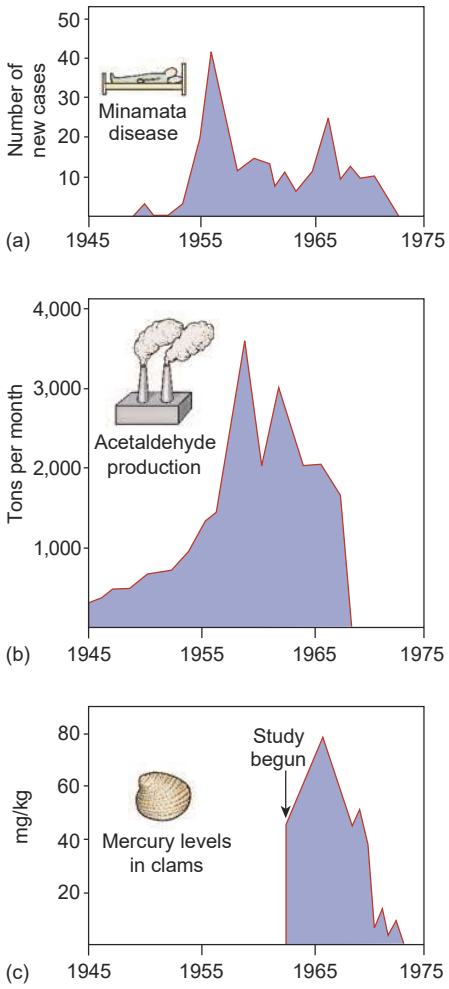


FIGURE 18.11 In the 1950s and 1960s a neurological disorder that often ends in severe brain damage, paralysis, or death appeared among the inhabitants of Minamata, Japan. The number of new cases (*a*) was directly related to the production of acetaldehyde by a chemical plant (*b*). A mercury compound was used in the production of acetaldehyde and vinyl chloride, which are used in making plastics. As a result, an estimated 200 to 600 tons of waste mercury were discharged into Minamata Bay between 1952 and 1968, when it was finally stopped. The disease, now called Minamata disease, was caused by eating seafood contaminated with mercury, here indicated by its concentration in the edible clam *Venus* (*c*).

Mercury and lead compounds are highly toxic. They are persistent and accumulate in the food chain.

Cadmium and **copper** are other toxic heavy metals that are slowly concentrated in marine life. Mining and refining operations are major sources. Cadmium is also present in the waste from battery manufacturing and in discarded batteries. Together with lead, mercury, and other toxic metals, cadmium is common in discarded computers and other electronic components. These toxic metals often seep into rivers or the ocean from disposal sites. Sources of copper include wood treatment and other industrial processes. Unlike lead and mercury, which are transported in the atmosphere, unnaturally high levels of cadmium, copper, and most other heavy metals remain localized near their source.

Radioactive Wastes **Radioactive** substances have been contaminating the marine world since the first atomic bomb explosions in the early 1940s. **Radioactivity** is a property exhibited by certain atoms that emit **radiation** in the form of energy or particular types of particles. Exposure to some types of radiation is harmful to all forms of life. In humans it causes leukemia and other cancers, as well as other disorders. Radioactive waste does not need to be ingested to have effects because it can penetrate through living matter. Radioactive material also may continue to emit radiation for thousands of years. Some radioactive **isotopes** occur in nature but in minute amounts, and some harmful radiation reaches us from outer space. A source of radioactivity is a by-product, or waste, of the use of the atom as a source of energy.

Radioactive waste is dangerous and must be disposed of somewhere. Some is stored in containers and dumped into designated areas of the ocean. Sunken nuclear-powered submarines and ships, fallen satellites, and crashed planes carrying nuclear weapons are other potential sources of radioactive waste. Accidents in nuclear reactors along the coast and industrial effluents add to the risk. Nevertheless, the use of radioactive material is highly regulated, so it generally poses no major threat to the marine environment.

Solid Waste

A look at the upper reaches of many beaches will reveal an amazing assortment of trash brought in by high water. Most of it is plastic: bottles, bags, foam cups and packaging, nets, and thousands of other items. Add rubber, glass, and metal and you have quite a heap of trash. Solid waste from land still flows to sea at an alarming rate, even if dumping of solid waste and other pollutants is banned by the London Convention of 1972.

FIGURE 18.12 It has been estimated that plastic debris kills as many as 2 million seabirds and 100,000 marine mammals every year. Plastic bags kill sea turtles that swallow them, thinking they have caught a jellyfish. Six-pack rings easily ensnare seabirds, which, unable to feed or fly, face a slow death. This California sea lion (*Zalophus californianus*) is being slowly strangled by nylon fishing line.

FIGURE 18.13 The Steller's sea cow (*Hydrodamalis gigas*), weighing an estimated 10 tons or more, ate mostly kelp. It became known to science in 1741, when it inhabited the kelp beds of the Commander Islands in the western Bering Sea. Demand for its meat, which was considered "as good as the best cuts of beef," led to its extermination at the hands of whalers. The species was slaughtered to extinction soon after its discovery; the last known live individual was taken in 1768.

Plastic is especially troublesome because it is strong, durable, and non-biodegradable. Styrofoam and other plastics eventually break down into tiny particles that are now found in every remote corner of the ocean. They have been found in the guts of many animals that ingest them by mistake. Seabirds are particularly vulnerable. Larger plastic debris is also a threat. Sea turtles, seabirds, seals, and others are maimed or killed after getting entangled in plastic fishing line (Fig. 18.12). Many die with their digestive tract clogged with plastic bags and other debris.

Thermal Pollution

Seawater is often used as a coolant in power plants, oil refineries, and other industries, many of which are built along the coast. The heated water that results from the cooling process is pumped back to sea, causing alterations to the environment known as **thermal pollution.** Local warm pockets can be created in poorly mixed bays. Even though some fishes may be attracted to the site, such temperature increases are known to adversely affect some organisms. Higher temperatures also decrease the ability of water to dissolve oxygen. The effects of thermal pollution on marine life are especially pronounced in the tropics. In contrast to organisms living in temperate and polar regions, corals and some other tropical species normally live just below the highest tolerable temperatures. Reef-building corals are particularly sensitive (Fig. 18.3).

Saline brines from desalination plants that are used to obtain fresh water from seawater are a major pollutant in the Persian Gulf and some other coastal regions. Brines are typically warmer than coastal waters and highly saline as well.

Thermal pollution results when heated water is pumped into the sea.

THREATENED AND ENDANGERED SPECIES

The alteration or destruction of habitats by humans may have another disastrous effect: driving species to their eventual disappearance, or **extinction,** from the face of the earth. Organisms become adapted to changes in the environment as a result of **natural selection.** If they cannot adapt, they go extinct. Extinction is therefore a natural consequence of the process of evolution. To make a distinction, some biologists refer to human-induced extinction as **extermination.**

Species that face extinction are classified as **rare** when they are not in immediate danger but are at risk, **threatened** when their numbers have become low, and **endangered** when in immediate danger of disappearing forever.

Marine species may be threatened by overexploitation for food, hides, and other products. Many species of fishes, sea turtles, and other marine animals are killed and discarded as fisheries by-catch (see p. 388). Habitat destruction, pollution, and the introduction of pests (see "Biological Invasions: The Uninvited Guests," p. 414) and diseases also place species at risk. The Steller's sea cow, a **sirenian,** is a shocking example of a marine animal that was rapidly exterminated because of unregulated hunting for food (Fig. 18.13).

Species are categorized as rare, threatened, or endangered when they face the possibility of extinction, or extermination.

Isotopes Different atomic forms of an element.
• Chapter 2, p. 32

Natural Selection The production of more offspring by those individuals in a population that are genetically best-adapted to the environment.
• Chapter 4, p. 79

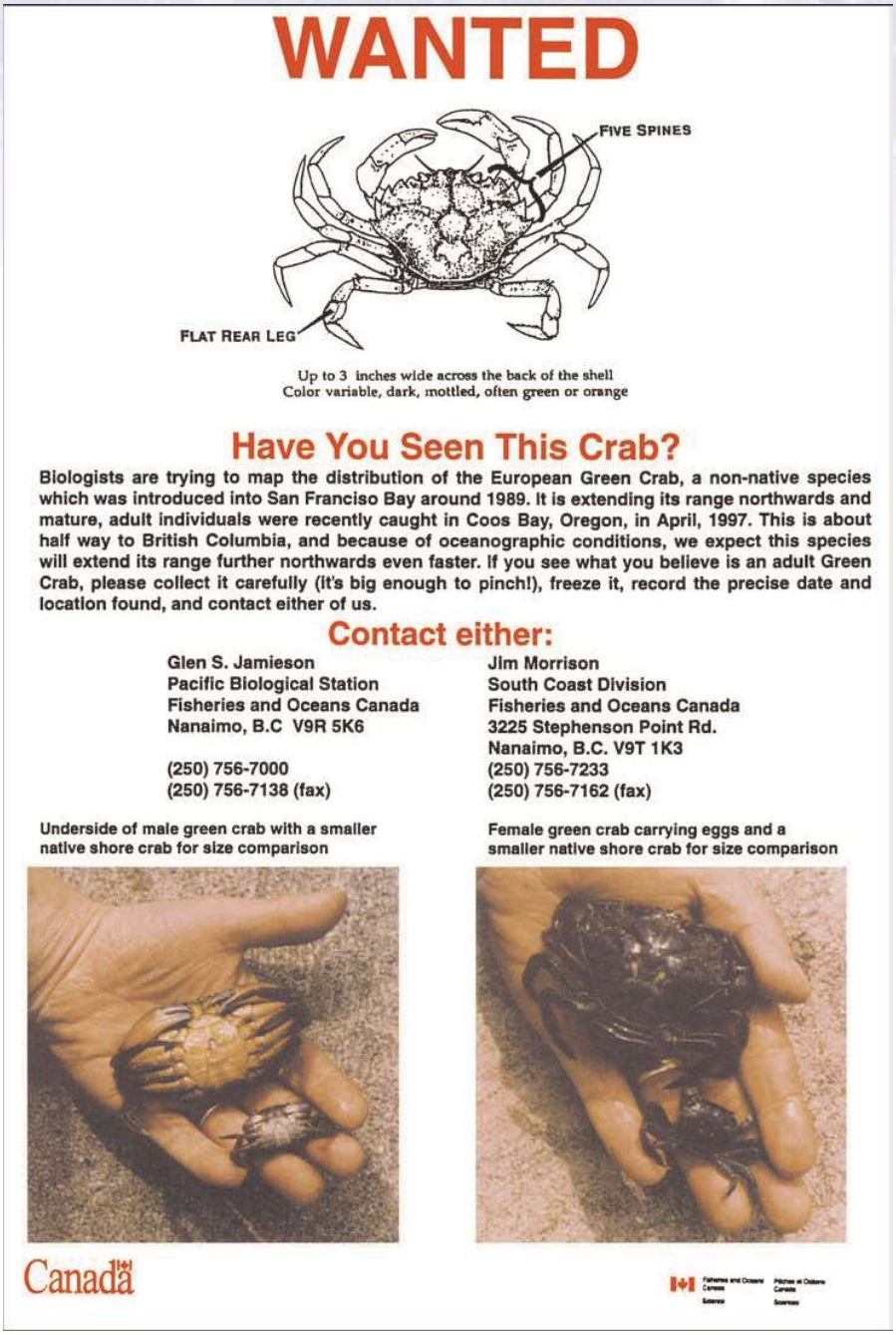
Sirenians A group of marine mammals collectively known as the sea cows having a pair of front flippers, no rear limbs, and a paddle-shaped tail.
• Chapter 9, p. 187

Biological Invasions: The Uninvited Guests

The deliberate or accidental introduction of **invasive species** in areas where they do not naturally occur can have devastating effects on the marine environment. One such effect has been the drastic reduction in the number of individuls belonging to **native,** or local, **species.** Invasive species, also known as **introduced** or **alien species,** often prove to be very strong competitors for food and space, and they can bring with them parasites that may infect native species. There has been an increase in the frequency of unwanted invasive marine species during the past few decades. It is the result of growth in shipping, the introduction of shellfish and fish for farming, and even the marine aquarium trade.

Bays and estuaries, especially those with busy ports, are particularly vulnerable. Seaweeds and invertebrates like sponges, barnacles, and sea squirts that grow as fouling organisms, which bore into or encrust on boats, pilings, and other underwater structures, have become established around the world. Many other species have been introduced as planktonic larvae in ballast water, which is used to fill ships' ballast tanks for stability. Others have been introduced with commercial fishery products, particularly shellfish. One good example is the Asian clam (*Potamocorbula amurensis*) that was accidentally introduced in San Francisco Bay, California, apparently as a direct result of the opening trade with China. These clams did not live in the bay in 1985, but by 1990 they literally covered whole sections of the bay's muddy bottom. As many as 10,000 clams per square meter carpet the bottom in some sections.

About 250 marine and estuarine invasive species have so far been found in San Francisco Bay. It's actually difficult to find a native species in some parts of the bay. Not only is San Francisco a busy port, but the bay is much disturbed. It is probably easier for an invasive species to become established when the environment is off balance. Many invaders do well in such unstable environments because they are often more tolerant than native species to wide fluctuations in factors such as salinity.



The future of many marine species is at stake (Table 18.1). Perhaps the most widely known case is that of the whales (see "Whaling," p. 194), but there are many other examples. Giant clams (*Tridacna;* see Fig. 14.34) are taken for food and for their shells in such numbers that they have become rare or even locally extinct in most of the tropical Pacific. Marine snails like cowries (*Cypraea*) and cones (*Conus*), whose shells are eagerly sought by collectors (Fig. 18.14), have similarly disappeared from many areas. Intense commercial fishing to satisfy the growing markets for shark meat and fins, recreational fishing, and by-catch on longlines threatens many species of sharks. Sharks, like whales, reproduce slowly. It is

One of the more recent invaders to San Francisco Bay is the European green, or shore, crab (*Carcinus maenas;* see Fig. 7.38). It was first recorded in the bay in 1989, probably introduced as larvae in ballast water. It soon extended its range along stretches of the Pacific coast. The green crab has also been introduced, and has become a pest, in the northeastern coast of the United States, Australia, and South Africa. The green crab lives in a wide range of salinities. It is also a voracious predator, feeding on commercially valuable oysters and young Dungeness crabs.

Another notorious guest is a comb jelly (*Mnemiopsis leidyi;* see Fig. 7.12) that was accidentally introduced in the Black Sea. It normally occurs along the coasts of North and South America. First recorded in the Black Sea in 1982, it has become a monumental pest, practically taking over the sea. It not only competes with fish for zooplankton food but also feeds voraciously on fish eggs and larvae. Along with overfishing, its impact on the Black Sea fisheries has been devastating. Fish catches have sharply decreased, causing huge economic losses in the area. And yes, it has been found in San Francisco Bay, too!

More than 250 species of invertebrates and fishes have migrated from their original home in the Red Sea to the Mediterranean. These species migrated by way of the Suez Canal, which opened in 1869 to provide the shortest sea route between Europe and the Indian Ocean. The 160-km (100-mi) journey through the canal is getting easier because the high salinity of the lakes through which the canal passes has decreased, thus becoming less of a barrier to planktonic larvae brought in by tides. Most migrants have moved from the Red Sea to the Mediterranean because the high tide carries larvae further up the canal from the Red Sea. The migration of these invasive species has been called Lessepsian migration after the builder of the canal, Ferdinand de Lesseps. Migration between the Atlantic and Pacific oceans across the Panamá Canal has not taken place (except a species of barnacle) because only fresh water flows through the canal, killing any marine life that is brought in by the tide (also see Fig. 9.4).

Seaweeds have also been accidentally introduced. *Codium fragile,* a green seaweed, apparently brought over on oysters transplanted from Europe or the Pacific coast, has become a pest by growing in masses on rocks and oysters on the northeastern coast of the United States. *Caulerpa taxifolia,* a green seaweed that grows into branches as long as 3 m (9 ft), was accidentally introduced in the Mediterranean from the Caribbean in 1984. This fast-growing seaweed has spread rapidly, particularly in the western Mediterranean, where it smothers seagrasses and other native species and depletes oxygen from the bottom. Unfortunately, the bright-green seaweed is widely used in marine aquaria. Its importation into the United States was banned in 1999, but in 2000 it was found in shallow water off Southern California, perhaps the result of someone emptying a fish tank into a storm drain. Other invasive seaweeds include *Caulerpa brachypus,* which smothers and kills corals in Florida, and several red algae introduced in the Hawaiian Islands (species of *Kappaphycus* and *Eucheuma denticulatum;* see Fig. 14.14).

Inland waters have not escaped uninvited guests. The small freshwater zebra mussel (*Dreissena polymorpha*) was introduced, probably in ballast water from Europe, in the Great Lakes. It was first found in 1988 but quickly spread. It is now found in all five Great Lakes in North America, the Hudson River estuary, and the Ohio River drainage basin as well. The clam has taken over the shallow-water bottom in many areas. It has caused costly damages because it disrupts water supplies by invading water-intake pipes.

The intentional introduction, or **transplantation,** of species for commercial purposes can also bring in invasive species. The Japanese oyster (*Crassostrea gigas*) was introduced as spat, or young individuals, on the Pacific coast of North America. It was a successful transplantation in the sense that the oyster is now of significant commercial value. Unfortunately, many species living on the spat shells were also introduced. A nasty invasive species is an oyster drill (*Ceratostoma inornatum*), a marine snail that preys on oysters and other native bivalves. Also introduced was *Sargassum muticum,* a Japanese brown seaweed that is now established from British Columbia to Southern California. The same species has also been introduced in England, probably with transplanted Japanese oysters. Species of cordgrass like *Spartina alterniflora,* from the Atlantic coast of North America, have caused problems in many regions worldwide when transplanted by spreading over mudflats, oyster beds, and eelgrass beds (see "Biological Control of Invasive Cordgrass," p. 276).

Another potential source of invasive species is the release into the ocean of marine aquarium fishes. Aquarium owners are suspected of releasing venomous lionfishes (*Pterois;* see Fig. 8.10c) and other Pacific aquarium fishes into the Atlantic coast of the United States. The seemingly harmless introductions may be horror stories in the making. It remains unknown if these fishes have been permanently established but lionfishes are known to reproduce in their adopted home. Local fishes and invertebrates cannot recognize these predatory fishes, and harmful parasites may have also been introduced.

It is difficult to prevent the introduction of uninvited guests. One possible option is to control or regulate the use of ballast water. The use of filtered or sterilized ballast water or the exchange of ballast water in mid-ocean far from land has been explored. The transplantation of species from different geographical regions must also be strictly regulated. Rigorous studies of the biology of the species involved and those in the proposed new locations should also be undertaken before such transplantations are carried out.

feared that many shark species may be pushed to the brink of extinction in a decade or two. All seven species of sea turtles are endangered. Adults as well as eggs have been exploited for food and tortoiseshell (Fig. 18.15; also see "The Endangered Sea Turtles," p. 180). Their nesting sites have been overrun by development, and they drown in fishing nets.

Seabirds have not fared well, either. Overfishing has been responsible for a decline in the number of seabirds in many parts of the world as a result of the decline in food. Longline fishing kills around 100,000 albatrosses (*Diomedea*) a year in Antarctic waters alone. Nineteen of the 22 species of albatrosses are threatened or endangered, some critically so.

Table 18.1 Endangered and Threatened Marine Species

Group of Marine Animals	Red List of Threatened Species, 2006[1] (Critically Endangered, Endangered, and Threatened Species)	CITES List of Species Threatened with Extinction, 2006[2]	CITES List of Species Vulnerable to Exploitation, 2006[3]
Corals and other cnidarians	3	0	All scleractinian, black, blue, organ-pipe, and hydrozoan corals
Other invertebrates	12	0	0
Marine molluscs	79	0	9
Marine fishes	795	2	48
Sea turtles	7 (all)	7 (all)	0
Marine iguana	1	0	0
Seabirds	297	5	1
Sirenians	4 (all)	3	0
Seals, sea lions, walrus	31	3	8
Sea otter	1	1	0
Polar bear	1	0	0
Whales, marine dolphins	77	24	1

[1]Compiled by the International Union for Conservation of Nature and Natural Resources.
[2]Appendix I, Convention on International Trade in Endangered Species of Wild Flora and Fauna.
[3]Appendix II, Convention on International Trade in Endangered Species of Wild Flora and Fauna.

Many marine mammals that have low reproductive rates also face extermination. Some species of seals, sea lions, and the walrus have been decimated for their skins, meat, blubber, or the precious ivory of their tusks. Monk seals *Monachus* are endangered; one species, the Caribbean monk seal *M. tropicalis*, is most probably extinct. The number of Steller sea lions *Eumetopias jubatus* has sharply declined in the northwestern Pacific. The sea otter (*Enhydra lutris;* see Fig. 9.12) had made a comeback but its numbers have been declining and it is still threatened (see "Kelp Communities," p. 296). Manatees (*Trichechus;* see Fig. 9.13) and the dugong (*Dugong dugon*), the smaller cousins of the extinct Steller's sea cow, are both in danger of extinction.

Many marine species are at risk of being exterminated because of unregulated exploitation and other anthropogenic impacts. Whales, sea turtles, manatees, and other marine mammals are especially imperiled.

CONSERVING AND ENHANCING THE ENVIRONMENT

There is increasing evidence for the loss of biodiversity through the disappearance of species as a result of the loss and degradation of habitats (see "Biodiversity: All Creatures Great and Small," p. 215). Conservation of biodiversity aims at the conservation of a vast number of species, their habitats, and entire communities, not merely the preservation of a limited number of endangered species.

Conservation

The protection, or conservation, of coastal areas from the advancing wave of development is of crucial importance. A growing human population (see Fig. 17.2) and the increasing demands of practically everyone exert continuous pressure on the natural environment. The apparent conflict between economic development and the protection of coastal resources, though especially intense in developing countries, occurs everywhere. Development should be **sustainable,** that is, it must meet the needs of today without affecting the ability of future generations to meet their needs. Laws have been passed by many governments, but there is still a lot to be done. **Coastal management** aims at promoting the wise use of our coasts while ensuring that the benefits of this use can be sustained for future generations. The multiple use of coastal resources

FIGURE 18.14 Reef-building corals for sale to tourists at a beach in Madagascar.

FIGURE 18.15 One of the many types of tortoiseshell products that are regularly confiscated by the U.S. Fish and Wildlife Service. They are part of the illegal multimillion-dollar world trade in endangered species.

and the need to manage them calls for judicious planning to accommodate the often conflicting interests of developers, fishers, surfers, power-plant builders, beachgoers, and nesting seabirds. Coastal management deals with issues as varied as historical preservation, beach access, military uses, tourism, and water quality.

Efforts to stop the deterioration of the marine environment include conservation and effective coastal management.

Conservation efforts include many local, national, and international projects (Fig. 18.16) and legislation dedicated to the protection of species and environments. Oil drilling, for instance, has been banned along some coasts, as in California. Commercial fisheries are regulated by national governments, partly as a result of the establishment of **exclusive economic zones,** or **EEZs,** and by international commissions (see "Managing the Resources," p. 389). Unfortunately, many stocks are still being harvested at levels above **maximum sustainable yields** (see Fig. 17.10). Governments have also established **marine protected areas** for the protection and management of areas of ecological significance. The National Estuarine Reserve Research System of the United States, for example, designated 17 reserves in 14 states and Puerto Rico protecting almost 1,200 km^2 (3,100 mi^2) of estuaries, salt marshes, and mangrove forests. The Great Barrier Reef in Australia, the Florida Keys, and other areas around the world have been designated marine protected areas. The world's largest marine reserve, the Northwestern Hawaiian Islands Marine National Monument, was created in 2006. It protects pristine coral atolls, which are inhabited by several threatened and endangered species, as well as the surrounding waters, a total area of around 360,000 km^2 (nearly 140,000 mi^2) northwest of the main Hawaiian Islands. Twenty-nine marine protected areas were also designated along the central coast of California the same year. Marine protected areas are usually richer in both the number and the abundance of species compared with unprotected waters around them. There is some evidence that protected areas benefit surrounding waters through either "seeding," in which the offspring of individuals inside the protected area settle elsewhere, or "spillover," in which juveniles and adults move out of the protected area. Only a tiny fraction of the ocean, 0.5%, is protected, however.

Groups and organizations like the World Wildlife Fund, the United Nations Environment Programme, The Nature Conservancy, and the Sierra Club play an active role in conservation through education, the sponsoring of projects, and even lobbying for legislation.

FIGURE 18.16 Biologists tagging a hawksbill turtle (*Eretmochelys imbricata*) in Papua New Guinea to learn more about its migrations and habits. Papua New Guinea is the only place with breeding grounds for six species of sea turtles. This photograph was taken at Wuvulu Island, where sea turtles are common because the inhabitants do not eat turtle meat and eggs as a result of religious restrictions.

Restoration of Habitats

Another strategy for improving the quality of the environment is to help habitats recover from modifications caused by habitat destruction and pollution. **Habitat restoration** helps recovery from stress by transplanting, or restocking, key species from healthier areas. The loss of priceless salt marshes and mangrove forests through landfilling or the building of boat marinas can be at least partially compensated for by creating or improving a similar but unstressed habitat elsewhere. These efforts, of course, assume that the new location meets the physical requirements (such as tides, salinity, and the type of substrate) for the development of a healthy biological community.

Successful examples of habitat restoration include the transplantation of cord grass (*Spartina*), one of the dominant plants of salt marshes, and of mangrove seedlings. Introduced species of cord grass, however, have taken over habitats normally inhabited by native species (see "Biological Control of Invasive Cordgrass," p. 276). Restoring salt marshes has been facilitated by reopening blocked connections to the open sea in order to restore tidal flow. Channels are constructed and

Exclusive Economic Zone (EEZ) A zone 200 mi (370 km) wide along the coast, in which nations have exclusive rights to fishing and other resources.
• Chapter 17, p. 390

Sand on the Run, or What to Do with Our Shrinking Beaches

Sandy beaches constitute one of our most valuable coastal resources. Millions use them for recreation, and their importance as a tourist attraction is evident from Atlantic City to Waikīkī. Unfortunately, beaches have been shrinking and disappearing everywhere.

Sandy shores happen to be among the most restless of all marine environments. Sand shifts, so disruptions like storms, hurricanes, winds, and currents periodically modify the shore. The Atlantic and Gulf coasts of the United States are protected by **barrier islands**—long, low, sandy islands that run parallel to the coast. This long stretch of islands constitutes one of the world's most splendid sandy beaches. Barrier islands are characteristic of shores bordering wide continental shelves. They were formed as sea levels began to rise between 12,000 and 14,000 years ago (see "Climate and Changes in Sea Level," p. 33). Waves and wind began pushing bottom sediments and formed bars on the flat shelf. Sand bars eventually formed barrier islands, which migrated toward the shore as the sea level rose.

The value of barrier islands goes beyond protecting coastline by absorbing the stress of hurricanes and currents. Their **sand dunes** are inhabited by salt-resistant plants and land animals. Seabirds use them as nesting sites. Barrier islands may include salt marshes, seagrass meadows, freshwater sloughs, and even forests. Florida's barrier islands feature mangrove forests. Untouched barrier islands, however, are becoming rare. Bridges and roads have made some more accessible, and as a result they have been overrun by development.

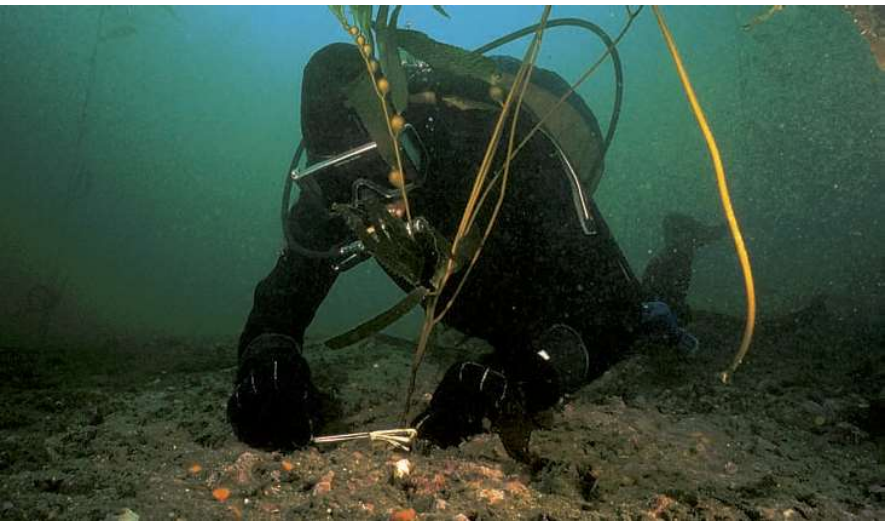
Effects of Hurricane Katrina, August 2005 (bottom), on a barrier island off the Louisiana coast.

Development is not the only concern. Their origin may give us a hint that barrier islands were not planned to be with us for a long time. Their size and shape are always changing. Wind and **longshore currents** erode their seaward side by continually shifting sand from one tip to the other, north to south in the eastern United States. Channels between islands may fill up, and previously damaged islands may be eroded away, as in the case of Hurricane Katrina in 2005.

Not everybody realizes that sandy beaches and barrier islands will not tolerate permanent structures for too long. Seawalls, breakwaters, jetties, and groins may be built as a safeguard but often make the problem worse. Erosion may be controlled by encouraging the natural development of dunes or by planting vegetation that helps stabilize the sand. Replenishing sand by bringing it periodically from offshore is one expensive, but temporary, way to save a beach. This is what is being done in highly urbanized Southern California, where rivers, which once brought in sand to the shore, now end behind dams or have been transformed into concrete-bottomed channels. Efforts to manage beaches and barrier islands, however, may only disrupt the natural coastal processes that sooner or later will triumph over our ingenuity.

accumulated sediment dredged. Tides slowly bring in the larvae of other components of the community. Young giant kelp (*Macrocystis*), with their root-like holdfasts tied to concrete blocks or to submerged nylon lines, have been used to help restore kelp forests (Fig. 18.17). New techniques in the transplantation of coral and seagrasses, promise the reseeding of damaged reefs and seagrasses. Seabirds are even being attracted to old nesting grounds by using painted decoys and solar-powered tape recorders that play bird calls!

FIGURE 18.17 Restoration of marine habitats has included the transplantation of young giant kelp plants (*Macrocystis pyrifera*) into areas where kelp forests have diminished or vanished.



Habitat restoration is nevertheless a poor alternative to preventing the degradation of marine environments. Restoration rarely if ever restores habitats to their natural condition, and it is usually expensive.

Conservation of marine environments includes the establishment of marine protected areas and the restoration of habitats.

Artificial Reefs

Fishing can be greatly enhanced by building **artificial reefs.** The irregular surfaces and the hiding places provided by the reefs attract fishes, lobsters, and other life, as well as anglers and divers. Shellfish and seaweeds

Five Simple Things You Can Do to Save the Oceans

Our impact on the health of the oceans is much more serious than we often assume. We all impact the oceans, no matter how far we live from the seashore. You can do a lot to help save the oceans and the rest of the planet. Here are five simple things inspired by *50 Simple Things You Can Do to Save the Earth* by the Earthworks Group and *50 Ways to Save the Ocean* by D. Helvarg.

1. *Take care of the environment.* If you go to the seashore or go snorkeling or diving, do not disturb the environment in any way. Respect natural habitats. Return any overturned rocks to their original positions. Leave all forms of life where they are. Ask questions when buying fish or ordering it at a restaurant: Where is it from and how was it caught? Buy fish certified as sustainably caught (check for the blue or white label from the Marine Stewardship Council). Eat lower on the food chain (shellfish, squid) and less or no swordfish, tuna, shark, and grouper. If you go fishing, target species that are abundant and not those that are overfished, even if it's legal. Know the regulations and take only what you really need for food. Return undersized fish. If you travel overseas, don't buy products made from endangered or threatened species like tortoiseshell or ivory, which may come from walruses. Corals and shells should be left alone, and alive, in their natural home. Be sure to tell merchants you object to their sale of shells, corals, sand dollars, and other marine life, which were most probably collected alive and killed for sale. If you buy fishes, corals, and other marine life for your marine aquarium, be sure to check before buying if they were obtained in an environmentally responsible, sustainable way. Clean after your pets. Their feces may carry parasites that, if washed to sea, can infect marine mammals as well as humans.
2. *Save energy.* Saving on energy keeps carbon dioxide, a greenhouse gas that promotes global warming and acidification of seawater, out of the atmosphere. Get out of the car. Use public transportation or a bike more often. Get rid of your SUV (and save 12 tons of greenhouse emissions a year!) and get a smaller car or a hybrid. Tailpipe pollutants add to the nitrogen nutrients that cause eutrophication of coastal waters. *Save electricity.* Most power plants still burn coal to produce electricity, releasing more carbon dioxide (an electric drier produces an average of 3.6 pounds of carbon dioxide a day but drying clothes on a clothesline produces none!) plus more nitrogen compounds as well as mercury. Saving gasoline and electricity also reduces the need for oil and thus the threats of more offshore oil drilling and oil spills.
3. *Dispose of hazardous materials properly.* The list of toxic chemicals we use is endless, from heavy metals and pesticides to even PCBs. Reduce your use of toxic chemicals at home, which are in discarded computers and electronics, batteries, motor oil, paints, cleaners, and many other types of household trash. Dumping them on the ground, in the trash can, or down storm drains or letting them accumulate in land fills is likely to pollute wetlands, the ocean, or rivers, which drain into the ocean. Flushing them down the drain simply adds them to sewage, which may ultimately flush, untreated, into the ocean. Your local recycling center can tell you how to recycle hazardous materials.
4. *Recycle plastics. Use less of them.* Reduce the risk of plastics being washed to sea by recycling them. Don't forget to pick up any plastic you may have left around the beach. Cut open those six-pack rings before disposal; you don't know where they may end up. Properly dispose of snarled fishing line; never toss it at sea or on shore. Use reusable canvas bags to do your shopping instead of plastic bags, thousands of which get blown or thrown to the sea every day around the world.
5. *Get involved. Keep informed.* Be aware of and keep up with environmental issues. Read, ask questions, listen carefully. Numerous organizations, societies, and agencies are committed to help save our planet. Hear what they have to say and sponsor them. Make your voice heard. Vote for the oceans and the planet. Support marine protected areas.

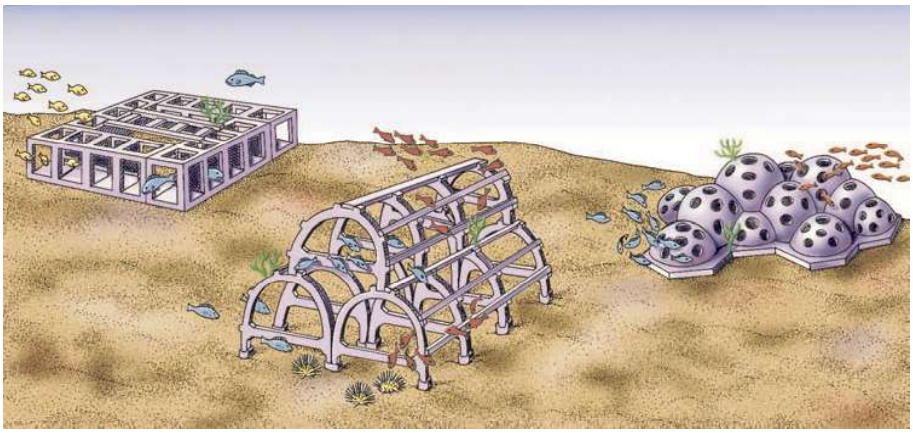


FIGURE 18.18 Artificial reefs can be built of various types of prefabricated concrete blocks.

like kelp can thrive on their surfaces. Everything from concrete blocks, discarded tires, and toilets to scuttled ships, useless battle tanks, an old 727 jet, and custom-made frames and structures have been used to build artificial reefs around the world (Fig. 18.18). Hundreds have been built in Japan, where *tsukiiso,* or reef-construction, has been successful in increasing commercial yields of fishes, abalone, sea urchins, and seaweeds. It has been argued, however, that artificial reefs may only concentrate fishes and wildlife in one spot, making them easier to catch and contributing to their depletion.