CHAPTER 9 HUMAN IMPACTS ON MARINE BIOTA

Humans change marine environments and affect marine organisms in many ways. We harvest marine plants and animals, carry out mariculture, reclaim land, dam rivers that run to the sea, and dredge harbours. Marine organisms are transported around the world, and are deliberately or accidentally introduced into new areas. The sea has long been regarded as a convenient dumping site, and various pollutants are released into the marine environment from domestic or industrial outfalls or from accidental spills. Coastal ecosystems become enriched from nutrients contained in sewage, in discharged detergents, and in agricultural runoff. All of these activities, and others, may change the species composition of marine communities, result in loss of marine organisms or loss of marine habitats, or disrupt whole marine ecosystems. A summary of some examples of human impacts is given in Tables 9.1 and 9.2.

Table 9.1 Major impacts of industrial activities on marine environments.

Activity	Impact location	Effects
Harvesting fish	World-wide	Changes in the species composition of pelagic and benthic communities Changes in size structure of targeted fish populations
Fishing methods	World-wide (depending upon specific types of fisheries)	Benthic trawling destroys bottom habitat Dynamite fishing destroys corals Unselective fishing increases discarded by-catch
Discard of by-catch	World-wide	Increase in scavenging species Acceleration in delivery of nutrients to deeper water Possible increases in benthic biomass
Dam construction	Rivers running to sea	Loss of habitat for anadromous fish
Urban development	Estuaries; coral reefs; mangroves	Land reclamation leads to loss of habitat Sewage disposal and agricultural runoff may cause eutrophication Industrial runoff may pollute coastal waters
Commercial shipping	World-wide	Introduction of species into new environments
Coral mining	Tropical reefs	Destruction of corals

QUESTION 8.21 What are some of the biological or ecological advantages conferred on organisms that live at great depths?

QUESTION 8.22 Of the two types of marine food chains described in the deep sea, one based on bacterial chemosynthesis and one on algal photosynthesis, which would be evolutionarily older? (Refer to the Geologic Time Scale in Appendix 1.)

QUESTION 8.23 (a) Which benthic communities are characterized by having many endemic species? (b) What reason(s) explain the high degree of endemicity in these communities?

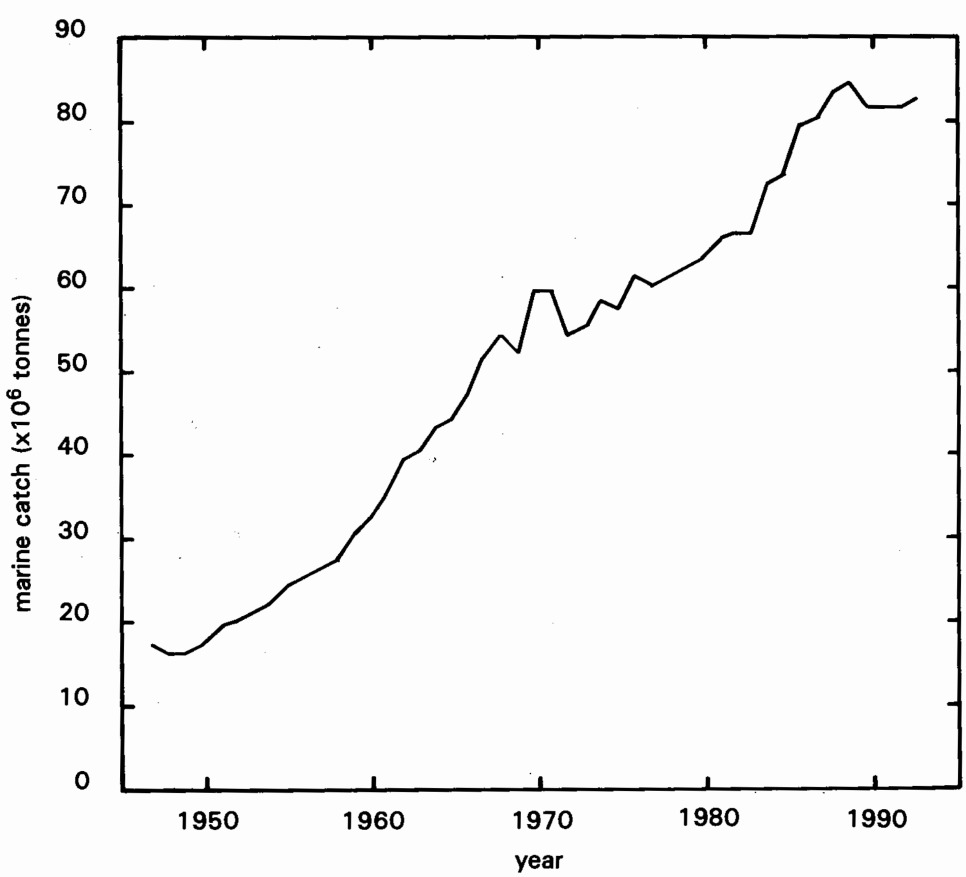
9.1 FISHERIES IMPACTS

What human activity has caused the greatest changes in the ocean?

The greatest and most serious human impact on marine ecosystems is caused by the annual removal of more than 100 million tonnes of fish and shellfish (reported catch plus by-catch, see Section 6.7.1). This harvest affects the species composition of pelagic communities as well as nutrient concentrations in surface waters (see discussion of f-ratio, Section 5.5.1). Mid-water and benthic communities may also be impacted by the dumping of dead by-catch which delivers a rich source of nutrients to deeper waters. There are also disruptive habitat changes caused by bottom trawling.

Advances in fishing technology have made it easier to locate fish schools and to catch more fish more effectively. At the same time, the world fishing fleet has increased rapidly, doubling to about 1.2 million vessels between 1970 and 1990. Long lines with thousands of baited hooks may extend more than 125 km from a ship, and some mid-water trawl nets with a mouth gape of 130 m and length of 1 km are large enough to encompass the Statue of Liberty or to extend around 12 jumbo jetliners. In some cases, more than 80% of a commercially lucrative stock is removed each year. These facts are reflected in Figure 9.1 which shows the increase in marine fish catch from less than 20×10^6 tonnes in the late 1940s to about 85×10^6 tonnes in 1993;

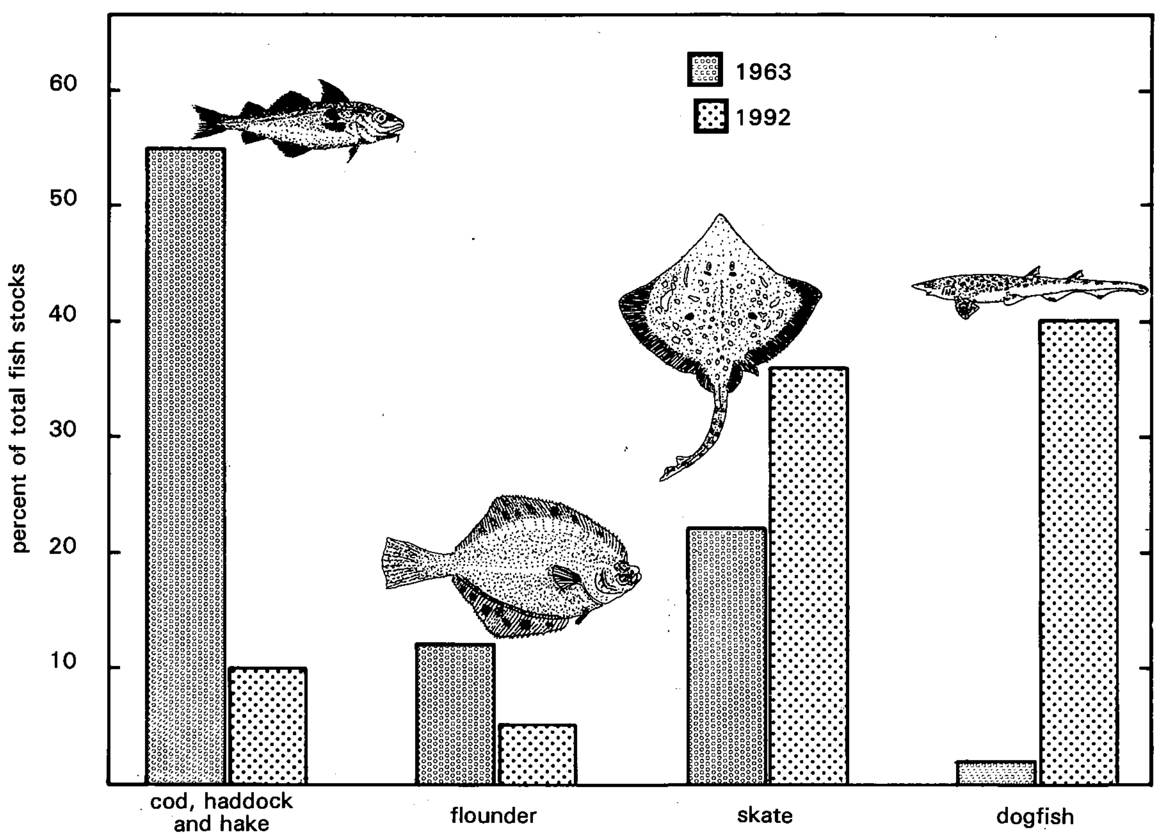
Figure 9.1 The marine fish catch (excluding by-catch) from 1947 to 1993, based on FAO statistics.



these figures do not include by-catch. However, it has become increasingly clear that many fish stocks throughout the world are now dwindling and that the **catch-per-unit-effort** (**CPUE**) of fishing has decreased. In the last two decades, fish catches have declined in all the major oceans except the Indian Ocean, where modern fishing fleets only began operating intensively in the late 1980s. A report issued by the United Nations Food and Agriculture Organization in 1995 concluded that 70% of the ocean's fish stocks are either fully exploited, overfished, or recovering from being overfished.

Although ocean climate change may be responsible for declines and changes in some fish stocks (see Section 6.7.2), overfishing is clearly responsible for the declines in many commercially favoured species. The 200-year-old fishery for cod and haddock stocks off eastern Canada and New England essentially ceased in the 1990s, although it may recover in time. Figure 9.2 shows how declines in these preferred species have resulted in changes in the abundance of other fish; skate and dogfish populations have increased by 35–40% since 1965, while cod, haddock, and hake have decreased by 45%. At the same time, less predation by cod and haddock on young lobsters has increased this lucrative shellfish harvest. Similar changes in community species composition have been documented in the North Sea, where sandlance greatly increased and became a target fish following declines in herring and mackerel stocks. In the Antarctic, commercial whaling and dramatic declines in the numbers of whales resulted in increased numbers of

Figure 9.2 Changes in the relative abundance of different fish species on Georges Bank, U.S.A., between 1963 and 1992, following overfishing of cod, haddock, and hake stocks. (Data from the National Marine Fisheries Service, U.S.A.)



other animals that were dependent upon krill for food (see Table 5.2). In the 1960s, commercial fisheries in the Black Sea targeted 26 species of fish, many of them large predators with long life cycles. Overfishing, construction of dams, and pollution have reduced this to only five commercially viable species, all of small size. On the other hand, the total biomass of the Black Sea fishery harvest has actually increased due to the greater abundance of smaller fish species whose populations are no longer kept in check by predation, and to increased fishing effort. Overfishing may also cause changes in size structure of fish populations; for example, the total weight of spawning Atlantic swordfish fell by 40% between 1978 and 1989. There are also examples of declines in shellfish populations due to a combination of overexploitation and coastal pollution. Within 30 years, oyster catches in Chesapeake Bay, in the eastern U.S., fell from 20 000 to 3000 tonnes.

Anadromous fish, such as salmon, are adversely affected by the dams that block access to spawning areas. Despite expensive efforts to enhance stocks through hatchery rearing and construction of runways around dams, salmon stocks in the eastern North Pacific Ocean have declined in some rivers (e.g. the Columbia River). Loss of coastal spawning grounds and nursery areas through land development and/or pollution is another increasing problem for many fish species. Fishing activities may also destroy habitats. Heavy fish trawls can penetrate 6 cm or more into the seabed, thereby disrupting the natural substrate and releasing nutrients into the water column, and destroying zoobenthos that may be food for the demersal fish stocks. In particularly rich fishing grounds, more than 70% of the sediment can be ploughed by trawls.

Commercial fisheries discard about one of every four animals caught; the percentage of this unwanted by-catch may in fact be larger because much by-catch goes unreported. The discarded catch includes species with no economic value and young fish that are too small to market. In some cases, the by-catch may exceed the target catch. Shrimp fisheries have an exceptionally large by-catch. The shrimp fishery in the Gulf of Mexico catches and discards at least 5 million juvenile red snapper annually, or 4.2 kg of fish for every 1 kg of shrimp. World-wide, the total by-catch of shrimp fisheries may be as much as 17 million tonnes per year; much of this is made up of small fin-fishes, most of which do not survive capture and release. Discarded by-catch increases the number of scavengers in fishing grounds. In the North Sea, it is estimated that the annual discarded by-catch of about 90 000 tonnes of whitefish can potentially support about 600 000 gulls.

Unfortunately, as a valuable fishery species becomes more scarce, its economic value tends to increase. Thus it often remains profitable for fleets to continue to take an overfished species. Spawning populations of bluefin tuna (the world's most valuable fish) have declined by about 80% in the western Atlantic since 1970, and by 90% in the Gulf of Mexico since 1975, but a single large specimen may fetch more than US $80 000 (about $265 per kg in 1996) on the market.

Declining world fish catches have alerted nations to the fact that it is indeed possible for man to deplete fish populations and to alter oceanic ecosystems over vast regions. Some progress has been made to alleviate the problems of overfishing; regulations have been set concerning allowable sizes and total catch for some species, driftnets have been largely banned, tuna fishers have adopted new methods to avoid capturing and killing dolphins, and whales are no longer the targets of commercial fishing. But international regulations are difficult to establish and to enforce on the open seas, and economic issues, not scientific management, continue to drive the industry. Hopefully the next decade will see the resolution of global fisheries problems before entire fish stocks and pelagic ecosystems are irrevocably changed.

9.2 MARINE POLLUTANTS

Marine pollution has been defined by the Intergovernmental Oceanographic Commission as the introduction by humans, directly or indirectly, of substances or energy sources into the marine environment resulting in deleterious effects such as harm to living resources; hazards to human health; hindrance to marine activities, including fishing; impairment of the quality of seawater; and reduction of amenities. The number of different pollutants entering the sea is very large, and new substances are added every day. Some of the substances regarded as pollutants, like heavy metals and petroleum hydrocarbons, occur naturally in the sea and human introductions add to natural concentrations. Some introduced pollutants will decompose in time or will be attenuated by the very large volume of the oceans, so that their effect will not be noticeable. Other pollutants may have significant impacts. Some of the major anthropogenic pollutants and their effects are summarized in Table 9.2 and discussed below.

Table 9.2 Some major forms of marine pollution and their effects.

Pollutant	Location	Effect
Petroleum hydrocarbons	Local oil spills	Mass mortality of benthos and seabirds
	World-wide seas	Low-level concentration effects unknown
Plastics	Beaches	Aesthetically disturbing
	Floating debris	Entanglement of animals; ingestion by animals
Pesticides and related compounds	Local point-source inputs	Acute toxicity
	World-wide seas	Long-term sublethal effects largely unknown
Heavy metals	Industrial outfalls	Mostly sublethal effects causing growth abnormalities
Sewage	Local outfalls; agricultural runoff	Eutrophication and altered community structure; introduction of pathogens
Radioactive wastes	Local power plants; historical at-sea dumping sites	Generally considered to be below harmful levels
Thermal effluents	Local power plants	Warming leads to altered community structure

9.2.1 PETROLEUM HYDROCARBONS

Petroleum hydrocarbons have probably attracted the most attention as marine pollutants because the impact of an oil spill is visually very apparent. Table 9.3 lists some of the major spills, the largest having occurred during the Arabian Gulf war when approximately one million tonnes of oil were spilled into the Gulf of Arabia. The largest spill from an oil tanker occurred when the *Amoco Cadiz* went aground off Brittany in 1978, releasing 220 000 tonnes of crude oil (Colour Plate 41). More than 300 km of shoreline were affected, causing the elimination of at least 30% of the marine benthic fauna and the death of some 20 000 birds. The effects of the *Exxon Valdez* spill (ca. 30 000 tonnes of oil) on Alaskan populations of birds and otters were noted in Sections 6.5 and 8.3. Although such large spills are devastating within localized areas, the natural recovery time of shoreline communities, under moderate conditions of wave action, is usually within 5 to 10 years for most organisms, although bird and otter populations may take longer to recover because of their slower reproductive rates.

Table 9.3 Some major oil spills in the ocean. (Italicized names are of oil tankers.)

Location	Source	Amount of oil spilled (tonnes)	Date
Arabian Gulf	Gulf War	1 000 000	1990–91
Gulf of Mexico	Oil well	440 000	1981
Brittany, France	*Amoco Cadiz*	220 000	1978
Cornwall, U.K.	*Torrey Canyon*	117 000	1967
Wales, U.K.	*Sea Empress*	70 000	1996
Japan Inland Sea	Storage tank	8–40 000	1974
Alaska, U.S	*Exxon Valdez*	37 000	1989
Northwest Atlantic	*Argo Merchant*	30 000	1976
North Sea	Oil well	15 000	1979

Tanker accidents are responsible for only a small percentage of the oil entering the sea. The production and transportation of oil, conventional shipping, waste disposal, and runoff are all additional sources of oil in the marine environment. There are also natural seeps, where oil deposits close to the Earth's surface leak into the sea. It is estimated that between 2.5 and 5 million tonnes of petroleum hydrocarbons enter the ocean each year from all sources. Over time, very small amounts (ppb) of petroleum hydrocarbons have accumulated world-wide in the oceans. The experimental toxic effect of such hydrocarbons is generally at concentrations of parts per million (ppm), and therefore the present accumulated background is not considered harmful to marine organisms, although effects of long-term chronic exposure to such concentrations are not fully known.

QUESTION 9.1 In what type of marine environment would you expect to find the slowest rate of recovery from a large oil spill?

9.2.2 PLASTICS

Discarded plastic materials in the oceans range in size from large nylon drift nets (see Section 6.2) to pellets of less than a millimetre in diameter which can be distributed by the wind over the whole ocean. These materials are not biodegradable; although plastics do break down as a result of physical and chemical weathering, this process is slow and therefore plastics accumulate over time in the sea. Loose driftnets (or 'ghost nets') or other discarded fishing gear, for example, can continue to entangle marine animals for years before washing ashore or sinking. Plastic bags or small plastic pellets are often mistaken for prey and ingested by marine turtles and seabirds, respectively. Pellets have been found in at least 50 species of marine birds. A survey of shearwaters (*Puffinus* sp.) in the North Pacific Ocean revealed that more than 80% of 450 birds had plastic particles in their stomachs. Ingested plastic bags are known to kill turtles; although one can speculate that ingested pellets may be harmful to birds or other marine life, there is presently no direct evidence to support this.

QUESTION 9.2 Can you think of any ways to reduce the amount of plastic material that enters the sea each year?

9.2.3 PESTICIDES AND OTHER BIOLOGICALLY ACTIVE ORGANIC COMPOUNDS

The most common pesticides entering the oceans are various forms of chlorinated hydrocarbons. These man-made compounds do not occur naturally, they are not readily degraded by chemical oxidation or by bacterial action, and they accumulate in animal fat tissues because they are lipid-soluble.

The best-known insecticide, DDT, was first employed in 1940, and within 20 years it and its residues could be found throughout the biosphere. Because DDT was often sprayed from aircraft, it was easily carried by winds into the oceans. Eventually even Antarctic penguins, living several thousand kilometres from any place where DDT had been used, were found to contain ppb traces of DDT. During the 1960s, there was increasing evidence that marine organisms, particularly seabirds, were being adversely affected in marine areas where DDT concentrations were exceptionally high. One example occurred off southern California, where a pesticide company had released DDT for 20 years into the coastal environment. DDT entered the ocean food chain, and its effects on the marine biota could be detected for 100 km along the coast. Fish in this area contained >3 ppm DDT, and pelicans and sea lions that fed on the fish accumulated even higher tissue concentrations of DDT and were unable to breed successfully. Even following a dramatic reduction in DDT emissions after 1971, DDT levels in fish remained high for years. Harmful effects were found in the Los Angeles Zoo in 1976, with the death of all the cormorants and gulls that had been fed inadvertently for several years on locally caught fish contaminated with DDT. Autopsy results found DDT concentrations ranging between 750 and 3100 ppm in liver tissues of these birds.

DDT usage has now been banned in some countries, but continues to be used in tropical areas as an effective control against mosquito populations that carry malaria. At present, most of the chlorinated hydrocarbon in the sea, and 80% of that in marine organisms, is in the form of DDE, a chemical derived from the breakdown of DDT. In most surface waters, DDT/DDE concentrations are between 0.1 and 1 ng l^{-1} (or less than one part per trillion), and these levels are not considered to be harmful. It is now recognized that heavy use of synthetic pesticides in agriculture is associated with significant undesirable side effects, and efforts are being made to find alternatives through biological or genetic controls of pests.

In addition to pesticides, several toxic chlorinated hydrocarbons are used industrially and may be present in seawater. These include dioxins and PCBs (polychlorinated biphenyls), both of which may have deleterious effects on marine life. PCBs are stable compounds that tend to persist in the environment and to be concentrated through biological processes. These characteristics were underscored by the discovery of exceptionally high PCB concentrations in several beluga whales that died in the St. Lawrence River in 1985; they contained up to 575 ppm in lipid tissue and 1750 ppm in the milk. The recognition of environmental problems has resulted in a ban on production and usage of PCBs in the United States. In the mid-1960s, the organo-tin compound tributyl tin (TBT) was found to have exceptional antifouling properties, and was consequently applied to boat hulls and fishing nets to prevent the settlement and growth of marine organisms. Unfortunately it leaches into surrounding waters, where concentrations between 0.1 and 100 $\mu g\ l^{-1}$ are toxic to the larvae of many benthic invertebrates, and levels as low as 0.001 $\mu g\ l^{-1}$ may affect reproduction in some marine snails. Ship traffic has spread TBT globally and the compound has accumulated in sediments near harbours and ports. Several countries have now established regulations designed to curb TBT usage.

9.2.4 HEAVY METALS

Heavy metals such as mercury, copper, and cadmium occur naturally in seawater at low concentrations, and they enter the sea through natural erosion of ore-bearing rocks and subsequent transport in rivers or via dust particles in the atmosphere, and through volcanic activity. All of these metals can be poisonous to organisms in high concentrations, and thus potential health problems exist where heavy metals accumulate in the sea around industrial outfalls, or at marine sites used to dispose of some types of mine tailings. At such localities, the local benthos may accumulate metals in levels exceeding permitted concentrations for marketable marine products (the permitted level for mercury is 1 ppm). Generally, heavy metals have acute toxic effects, but accumulations of these substances in marine animals may also cause chronic effects such as growth abnormalities, including cancers.

A serious case of heavy metal poisoning in humans occurred in Minamata, Japan, where a plastics factory discharged an estimated 200–600 tonnes of mercury over a period of 36 years into the local bay. Illnesses began to appear in the early 1950s, and by 1956 these were diagnosed as mercury poisoning derived from eating contaminated shellfish and fish from the bay. Effects included severe neurological damage, paralysis, and birth deformities. By 1988, 2209 victims had been verified, of whom 730 died. Following this tragic discovery of the dangers to human health from eating mercury-containing seafood, regulations were adopted in many countries to limit mercury discharges and to limit the tissue concentrations allowed in seafood products.

What are normal concentrations of mercury in the muscle tissue of pelagic fish?

Most species of fish in uncontaminated oceanic waters contain about 150 $\mu g\ kg^{-1}$ (0.15 ppm) of mercury in their muscles. However, some large pelagic species such as sharks, swordfish, black marlin, and tuna may have tissue concentrations as high as 1–5 ppm, but these levels are not indicative of anthropogenic pollution. These long-lived fish are large carnivores at the end of food chains, and their high mercury levels are acquired by bioaccumulation over their life spans.

Although other heavy metals, such as cadmium, copper, and lead, may accumulate in marine organisms exposed to high concentrations at waste discharge sites, they are not known to have caused serious human health issues. Problems arising from the use of another metal, tin, have been discussed in Section 9.2.3. International agreements now regulate marine discharge and usage of some of the more dangerous metals.

9.2.5 SEWAGE

Sewage disposal is a major form of coastal pollution throughout the world. Sewage outfalls near coastal communities release human waste as well as other organic matter, heavy metals, pesticides, detergents, and petroleum products. Nutrients from organic waste material may cause eutrophication; local waters may also be nutrient-enriched by detergents that contain phosphate and by agricultural and horticultural products entering from runoff. In addition, human sewage delivers pathogenic bacteria and viruses that are not necessarily killed by exposure to seawater; high concentrations of these microbes make local seafood unsafe to eat and contaminated waters unsafe for bathing. The chief health risk from sewage is through eating contaminated seafood, particularly filter-feeding clams or mussels which accumulate human pathogens on their gills. The cholera virus is a particular problem in some countries, and may be transmitted in just such a manner.

In urban areas of developed countries, sewage may receive special treatment to degrade organic matter or to remove nitrates and phosphates, but these processes are expensive. Usually no more sewage is treated than is deemed necessary, and in many places sewage is released into the sea without treatment. Generally the immediate area (within 100 m) around a large sewage outfall may be anoxic and dominated by anaerobic bacteria. At some greater distance from the outfall (within several km), nutrient enrichment typically leads to increased production of green macroalgae (*Enteromorpha* or *Ulva*) that form thick mats along the shoreline. A few opportunistic animals, such as the polychaete *Capitella*, are also indicative of sewage enrichment and may dominate affected benthic communities. At some ten kilometres from a major domestic outfall, there is usually sufficient attenuation of pollutants that community species diversity is not affected.

9.2.6 RADIOACTIVE WASTES

Radioactive wastes enter seawater from nuclear testing, from nuclear power plants or reprocessing reactors, or from deliberate dumping of waste materials. Heavy radionuclides have low solubility in water and tend to be adsorbed onto particulate matter; they therefore accumulate in sediments. Isotopes with long half-lives (e.g. caesium-137, strontium-90, and plutonium-239) are especially hazardous and are usually monitored in areas where they may escape from nuclear facilities. Barring major accidents, background levels in the marine environment around radioactive outfalls are generally regarded as safe. The potential for reaching high concentrations of radioactive materials exists in certain localized areas, notably around the several known sunken nuclear submarines, from nuclear dump sites at sea (which are now prohibited), and from nuclear testing that has been carried out within coral atolls (most recently in the South Pacific by France). However, it is predicted that leakage from such sources would occur at a slow rate and that there would be dilution of soluble radionuclides and adsorption of others on to bottom sediments.

Some marine organisms (e.g. seaweeds and bivalves) may accumulate radionuclides from surrounding water. For example, the alga *Porphyra umbilicalis*, growing in the vicinity of a reprocessing plant in England, accumulated 10 times the concentration of caesium-137 found in the ambient water and 1500 times the concentration of ruthenium-106. The experimental consequences of low-level doses of radiation on marine organisms are the same as those for terrestrial species and may include increased incidences of cancers, impaired immune systems, and genetic defects causing growth deformities. However, present levels of radiation in the sea have not produced any measurable environmental impact on marine biota.

9.2.7 THERMAL EFFLUENTS

Power plants may discharge several hundred thousand cubic metres of cooling water per hour into coastal waters, and this thermal effluent may raise the local seawater temperature by 1–5 C°. In some areas, this warmed water can be used beneficially to enhance growth rates of organisms grown in mariculture. However, in many cases elevated temperatures cause unwanted changes in the natural fauna and flora. For example, a persistent elevation of the ambient temperature by 5 C° along the subtropical Florida coast resulted in the replacement of natural algae and seagrasses by mats of cyanobacteria. In another example, the increase in water temperature of a temperate area of the U.S. allowed the entry of warm water wood-boring bivalves which caused damage to boats and wharves. In most cases, the area affected is limited to the plume of hot water and its immediate surroundings, an area that may range from less than one hectare to about 40 hectares.

There may be other effects from thermal effluents. They often contain chlorine, which is added to intake water to prevent fouling organisms from blocking pipes, and as little as 0.1 ppm of chlorine remaining in the effluent can be toxic to some organisms. Water flow of the plume also mechanically scours the seabed and so influences the fauna.

QUESTION 9.3 At what time of the year would you expect to have the greatest impact from thermal effluents released from power plants located on a subtropical coast?

9.3 INTRODUCTIONS AND TRANSFERS OF MARINE ORGANISMS

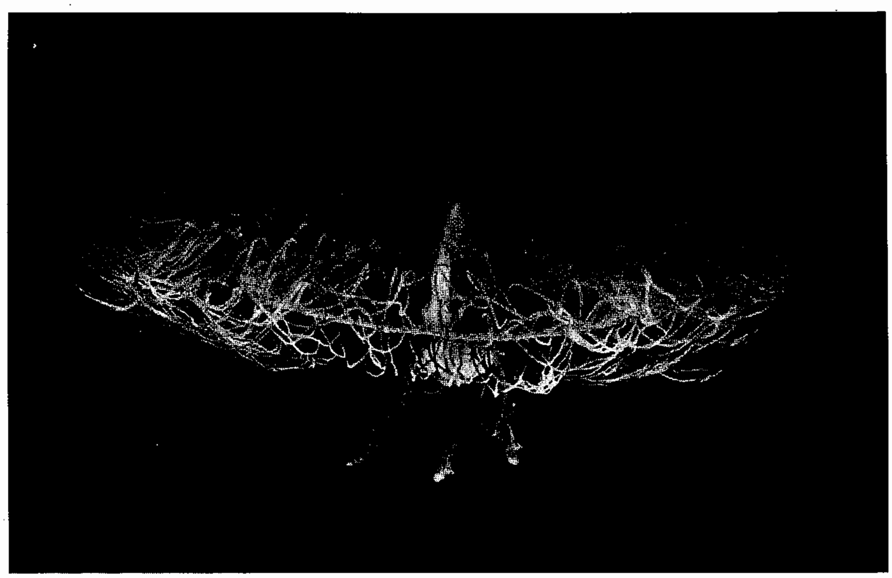
The movement of species from one region to another occurs naturally through larval drift, rafting, and other means, but humans have accelerated these movements and eliminated natural ocean barriers by accidental or deliberate introductions of species into new areas. In many cases, introduced species fail to develop reproducing populations, but in some instances an exotic species encounters favourable conditions and causes a significant impact on its new environment.

Marine organisms have often been introduced deliberately into new environments for mariculture purposes. For example, the Japanese oyster (*Crassostrea gigas*) and the east coast oyster (*C. virginica*) were brought to the north-west coast of North America because they were larger and grew more rapidly than the local oyster (*Ostrea lurida*); simultaneously, predatory snails that bore into oysters and other molluscs were accidentally introduced and both the oysters and this predator are now firmly established in this region.

Increased demand from the mariculture and aquaria industries and increased ship traffic have accelerated the rate at which species are transported to new environments. Each day, approximately 3000 species of marine animals and plants are being carried across oceans in the ballast tanks of ships that take on seawater in port and then release it at later ports of call. Examination of ballast water released in Oregon from a Japanese vessel contained 367 taxa of both holoplankton and meroplankton. Thus entire planktonic communities, including the larvae of benthic organisms, can be transported across natural oceanic barriers.

The release of the ctenophore *Mnemiopsis leidyi* (see Section 4.7) into the Black Sea is one example of an invasive species that encountered favourable conditions and no natural predators, and rapidly became so abundant in the Azov and Black Sea that it caused drastic declines in the resident zooplankton and subsequent declines in the anchovy fisheries of bordering countries. More recently, two species of jellyfish that are native to the Black Sea have appeared in San Francisco Bay (Figure 9.3); it is too early to assess their impacts on the ecosystem. Asian species of copepods are now present in Californian harbours, and the Chinese clam *Potamocorbula amurensis* has become one of the most abundant marine animals in the estuary of San Francisco Bay. The zebra mussel *Dreissena polymorpha*, originally from the Mediterranean, entered the North American Great Lakes from ballast water in 1986 and almost immediately began to grow in such

Figure 9.3 *Maeotias inexspectata*, a jellyfish native to the Black Sea that has recently been introduced into San Francisco Bay, California.



profusion that it blocked water intakes, resulting in an expense of ten billion dollars to deal with its destructive effects.

Australia has had over 35 successful invasions in recent years; the predatory starfish *Asterias amurensis* has invaded the coast of south-eastern Australia, and a common Japanese kelp, *Undaria pinnatifida*, is spreading along parts of Australia at a rate of 55 km a year. It is believed that the appearance of red tides (see Section 3.1.2) for the first time in Tasmanian waters resulted from toxic dinoflagellates being transported in ballast water of cargo ships; one such vessel contained more than 300 million toxic dinoflagellate cysts in the sediment accumulated in its tanks.

How could the spread of marine organisms by transport in ballast water be reduced?

Ships take on ballast water in coastal seaports. The problem of global transport of marine species could be ameliorated by requiring ships to exchange ballast water at sea. Coastal organisms are unlikely to survive in oceanic water, and oceanic organisms are much less likely to survive release into low salinity coastal water.

9.4 IMPACTS ON SPECIFIC MARINE ENVIRONMENTS

9.4.1 ESTUARIES

Many of the world's largest cities are located on estuaries; London, Shanghai, and New York are but a few examples. It is not surprising, therefore, that estuaries have suffered more from human impact than most other marine environments (see Figure 8.6). The most severely affected area is usually the saltmarsh community because this upper intertidal area is easily reclaimed for housing and industrial activity and, sometimes, for airport construction. In some localities, more than 90% of this community has disappeared. The deeper seagrass and mudflat communities are often disrupted by dredging operations to make large harbours and deepen shipping channels.

The same features that make estuaries productive also make them especially vulnerable to pollution. Just as nutrients are retained within the system (see Section 8.5), so are pollutants like petroleum byproducts, heavy metals, fertilizers, and pesticides. Both the plankton and benthic communities are affected by domestic and industrial outfalls releasing organic pollutants that may cause unwanted eutrophication. Pathogenic organisms, heavy metals, and pesticides that enter estuaries may all eventually work their way up the food chain into edible products for humans.

Because estuaries are naturally productive, they are often favoured fishing grounds and are frequently used for harvesting shellfish or for developing mariculture. Recently, however, many estuarine fisheries and shellfish beds have been closed due to high numbers of coliform bacteria from domestic sewage, or from the accumulation of pesticides or heavy metals in fish products. All of these forms of pollution may also alter the structure of the estuarine ecosystem so that traditional spawning grounds and nursery areas for fish may be lost. In extreme cases of pollution and eutrophication, anoxic zones may occur where only bacteria can survive.

Because of the dangers of human health risks from pollution of estuarine waters, monitoring programmes have been established in developed countries. Many pollutants occur in very low concentrations (ppb level) in seawater and are therefore extremely difficult to measure, even using sophisticated equipment and techniques. For this reason, a special programme called **Mussel Watch** was established to monitor concentrations of marine pollutants in mussels. This programme uses mussels (*Mytilus*) because they are abundant world-wide in coastal regions, because they are sessile animals that are exposed to any pollutants contained in the water flowing over them, and because these filter-feeding bivalves are known to accumulate a variety of pollutants. They have also been extensively studied, both experimentally and ecologically. Tissue levels of pollutants that have accumulated in mussels from contaminated areas can be more easily measured than pollutant concentrations in ambient waters, and these values can be compared with standards in mussels from uncontaminated regions. Since 1986 in the United States, mussels (or oysters) have been collected from over 200 localities once each year. Tissues are analysed for several heavy metals, chlorinated hydrocarbons including DDT and PCBs, and tributyl tin. Analysing these pollutants in mussel tissues is much easier and cheaper than analysing the same substances in trace concentrations in seawater.

QUESTION 9.4 . Drawing on your general knowledge of geography, can you think of any large estuaries in the world that do not have adjacent cities and are not affected by human populations?

9.4.2 MANGROVE SWAMPS

Mangrove swamps (see Section 8.7) suffer from many of the same environmental disturbances that are experienced by estuaries. Dredging, land reclamation, garbage and sewage dumping are all disturbances that can have significant impacts on mangroves near populated areas. In these tropical and subtropical ecosystems, insect control (particularly of malaria-carrying mosquitoes) has resulted in accumulations of pesticides in estuarine sediments and in mangrove food chains. During the Vietnam war, spraying of herbicides on mangrove swamps defoliated and destroyed as much as 100 000 hectares. Oil spills smother both algae and invertebrates, and disrupt the oxygen supply to the root system. Where river water has been diverted into irrigation systems, the reduction in freshwater discharge and the resulting elevated salinities may be detrimental; for example, a considerable area of mangrove swamp has been destroyed by diversion of water flow from the Indus River in Pakistan.

Overcutting of mangroves is, and has been for centuries, a serious problem in many areas. Mangroves once existed along the shores of the Persian Gulf, where they were a much-needed source of firewood for humans and of green fodder for camels in a desert environment, but they were eventually eliminated by overcutting. Some efforts had been made to re-establish mangroves along north-eastern Saudi Arabia, but these were destroyed by the Gulf War. Other countries, recognizing the benefits of mangroves, have also developed afforestation programs, reintroducing mangroves with varying degrees of success. Globally, however, destruction of mangroves is progressing faster than reintroduction. Almost half of the world's mangroves have been eliminated in recent years in order to build shrimp farms or rice paddies. In countries like Bangladesh, removal of this buffering zone has led to intensified coastline inundation and erosion from tropical storms.

Typhoons and hurricanes remain perhaps the greatest destructive agents of mangrove swamps, as they affect very large areas and occur frequently. Not only do they uproot trees, but severe storms alter the salinity of both water and soil, and they cause massive sedimentation. It is estimated that recovery of mangrove forests from very violent storms takes at least 20 to 25 years. Whereas little can be done to reduce damage from natural events, it is possible to develop management policies for the exploitation of mangrove resources, including replanting. The rational utilization of mangrove areas depends ultimately on increasing public awareness of the importance of this unique marine community to local populations in developing tropical countries.

9.4.3 CORAL REEFS

Coral reefs not only have great beauty and support a very high natural diversity with many endemic species, but they also have wider biological and economic importance. Because corals remove large amounts of bound CO_2 from the oceans during calcification, the reefs play a role in the global CO_2 budget. They are of benefit in protecting coastlines and providing sheltered harbours. And as air travel has become cheaper and more available, reefs have brought in more and more 'tourist dollars' to boost the economy of human populations living in their vicinity.

However, coral reefs are extremely vulnerable to disturbance, and reefs are presently regarded as declining. The World Conservation Union and the United Nations Environment Program (UNEP) reports damage or destruction of significant amounts of reefs in 93 out of 109 countries. Much of this destruction results from human activities, some from changes in ocean climate.

Expanding human populations near reefs often result in the addition of various types of pollutants to near-shore waters. These can include agricultural runoff, pesticides, industrial pollutants, and sewage from beachfront hotels or coastal communities. Many of these sources increase the nutrient concentrations in the seawater, and this eutrophication triggers outbursts of benthic algae that can outcompete corals for available space. Often the algae overgrow the corals, smothering and killing the reefs by cutting off the sunlight required by the zooxanthellae. Just such an event followed a burst of land construction and development in an area of the Hawaiian Islands. After thick mats of algae overgrew and killed large areas of the reef, the decomposition activities of bacteria led to a lowering of oxygen concentrations in the seawater. The final result was a dramatic decrease in diversity, with a particular sea cucumber becoming the dominant animal.

Various types of coastal development also result in increased land erosion, which then increases the amount of sediment in water overlying the reef. The suspended silt decreases light penetration, thus reducing photosynthesis of the zooxanthellae and diminishing a nutritional source for the corals. Although coral polyps are capable of removing some settling sediment, using mucus trapping and cilia to cleanse their surfaces, excessive quantities of silt will clog this apparatus and smother the polyps. Deforestation, leading to increased runoff and excessive sedimentation, is a major cause of coral reef destruction. Logging in one area of the Philippines (Bacuit Bay) has increased erosion and killed 5% of the area's reefs. Dredging to deepen harbours or open ship channels through the reef has similar effects on adjacent reefs.

A coral reef offers a number of resources used directly by humans. In some localities, coral is cut and used as a favoured building material (Figure 9.4). In the Maldive Islands (Indian Ocean), about 200 000 m^3 of coral rock have been mined in the past 20 years; this represents about one-third of the available coral in shallow water. This practice has also destroyed large areas of reefs in French Polynesia and Thailand.

Local inhabitants have traditionally relied on fish from nearby reefs as an abundant protein source, but demands have increased for this resource as populations have grown in size and as expanding numbers of tourists enter the communities. At the same time, private and public aquaria have increased in number throughout the world, and the capture of exotic fish for sale to the aquarium trade has become an extremely lucrative business, worth about $40 million per year (in 1996). To meet these increased demands, traditional fishing methods often have been replaced by much more detrimental techniques. It has become common to blast with dynamite to stun fish, which are then easily collected when they rise to the surface. At the same time, portions of the reef are destroyed, and it is estimated that it may take some 40 years for areas destroyed by blast fishing to recover to 50% live coral cover. Cyanide is also used to stun fish for live collection, although it may result in the death of the fish and certainly kills other reef species. In the Philippines alone, an estimated 150 tonnes of sodium cyanide is used annually for fish capture. Increased fishing, whether by traditional or non-traditional methods, has resulted in overexploitation of many species in many regions. Where destructive fishing techniques have been banned, regulations often are not enforced.

Fish are not the only reef inhabitants that are removed for consumption or trade. Corals are removed for ornamental purposes; about 1500 tonnes of such coral was imported into the United States alone in 1988. Spiny lobsters,

Figure 9.4 Mined coral that has been cut for building purposes in the Maldive Islands, Indian Ocean.

sea cucumbers, and sea urchins are among some of the reef animals that are considered delicacies in many parts of the world. Snails and clams are collected for food, or to sell to tourists and shell collectors. Removal of large numbers of animals from reefs may alter the ecology. For example, sea urchins are responsible for removing part of the reef framework during grazing; this bioerosion may be intensified when their natural predators (some fish and molluscs) are overfished.

Tourism may strengthen the economy of reef areas, but it often has the effect of damaging or destroying that very resource which people pay to see. Tourism leads to increased development, which may increase erosion and siltation over the reef, and it almost certainly increases the amount of sewage entering the water. As more tourists arrive, more fish is sold to restaurants and hotels, and more shells and coral are removed as mementos. Even seemingly innocent activities can have repercussions on the reef ecology. Reefs off Florida in the United States have been seriously damaged by amateur boaters colliding with submerged coral heads or anchoring to corals which are easily broken in the process. Even walking on reefs at low tide is destructive to coral. Tropical countries that wish to have long-term economic benefits from their local reefs would do well to avoid overexploitation, and to educate both local populations and visiting tourists.

In the 1970s, attention was drawn to Pacific reefs that were being destroyed by *Acanthaster planci*, the crown-of-thorns starfish. This large (30–40 cm diameter) echinoderm feeds on coral polyps, but is normally present in low enough numbers that reef damage is slight. However, *Acanthaster* began to undergo population explosions on many reefs in the western Pacific, including the Great Barrier Reef. Tens of thousands of starfish were found on some reefs, and the impact of so many large predators was devastating, with entire reefs being destroyed in some areas. For example, in less than three years, *Acanthaster* destroyed approximately 90% of the coral along 38 km of reef off Guam. Parts of the Great Barrier Reef have experienced major damage from predation during two separate starfish outbreaks, one in the 1960s and again in the 1980s.

Many causes have been advanced to explain the outbreaks of *Acanthaster*. These include increases in waterborne pollutants or increases in sedimentation due to dredging or other activities. It also was suggested that shell collecting was to blame. Many tritons had been removed from reefs, as the shell of this large snail is a prized ornament. Tritons are one of the few natural predators of the crown-of-thorns starfish, and the decline of these snails could result in lessened mortality of *Acanthaster*. It seems, however, that no one explanation applies to all the reefs damaged by starfish predation. There have been suggestions that *Acanthaster* density fluctuations may be natural cycles that are linked to ocean climate change. As with the similar kelp–urchin interactions discussed in Section 8.3, the debate continues about whether starfish population explosions are a contemporary phenomenon linked with human activities, or whether they are an ecological pattern that has persisted for thousands of years. In any case, restoration of coral cover takes place within 10 to 20 years, but it may take much longer to re-establish the original species diversity.

Storms, exposure during exceptionally low tides, and other natural events may cause widespread coral damage. In 1982–83, a rapid 2–4 C° rise in seawater temperature to nearly 30°C was caused by a particularly strong El Niño event, and this damaged or killed 95% of the coral in the Galapagos

Islands, and 70% to 90% of the corals in the Gulf of Panama and in Indonesia. In 1987, reefs throughout the Caribbean were affected by a similar event. Corals are particularly sensitive to elevated temperatures as they live so close to their upper temperature tolerance limits. Any sustained temperature increase usually results in bleaching due to loss of zooxanthellae, and eventually to death if the thermal stress continues. In Hawaii, bleaching of coral has been correlated with discharge of heated effluent from a power plant, and bleaching can be experimentally induced by elevated temperature. On a world-wide basis, global warming poses a serious threat to coral reefs.

Reef-building corals similar to modern species have a geological record dating back about 250 million years, but other types of coral reefs occurred as long ago as 500 million years. More than 5000 species of extinct corals are known, compared with the present number of less than 600 reef-building species. The pace of species extinction may be accelerating in many areas. Some countries, recognizing the benefit of adjacent reefs, have developed governmental policies to protect them. About 65 countries now have almost 300 protected areas that include coral reefs; these include marine reserves and underwater parks. The economic benefits of controlled tourism may push other countries to develop conservation policies.

9.5 SUMMARY OF CHAPTER 9

1 The annual fish harvest of more than 100×10^6 tonnes has had a greater impact on the ocean than any other human activity. By 1995, fish catches were declining in all major oceans except the Indian Ocean and 70% of the ocean's fish stocks were either being fully exploited, were overfished, or were recovering from being overfished.

2 The results of intensive fishing include: declines in targeted fish stocks and consequent changes in relative abundance of species; changes in size structure of fish populations; declines in pelagic and benthic animals captured incidentally as by-catch; acceleration of nutrient transfer to deep water through dumping of dead by-catch; increased numbers of scavengers in marine food chains receiving large amounts of by-catch; and destruction of seabed habitats through benthic trawling.

3 Fish stocks are also affected by construction of dams that eliminate spawning grounds (e.g. salmonids), and by loss of coastal spawning and nursery grounds due to land reclamation or pollution.

4 Human activities result in the release of a variety of pollutants into the sea. These substances, which may cause deleterious changes, include petroleum hydrocarbons, plastics, pesticides and related chlorinated hydrocarbons, metals, fertilizers, and radioactive wastes. Sewage outfalls deliver many of these pollutants as well as human wastes, detergents, and pathogenic bacteria and viruses. Power plants also release heated effluents that elevate ambient seawater temperatures.

5 Although oil spills are among the most visible types of marine pollution and ecological damage in the immediate site may be severe, populations generally recover within 5 to 10 years. In the open ocean, the accumulated concentration of petroleum hydrocarbons is too low to cause measurable effects.

6 Nonbiodegradable plastic materials are now found throughout the oceans. These include lost fishing nets, which may continue to entangle animals for years, and plastic materials that are mistaken for prey and ingested by turtles and seabirds.

7 Toxic synthetic pesticides like DDT and related compounds (dioxins, PCBs) that enter the marine environment are not readily degraded; they persist for long periods and enter marine food chains. Because they are stored in fat tissues, these compounds show biomagnification, with higher trophic level animals accumulating concentrations that may be lethal. Past incidences of pesticide and PCB poisoning in marine organisms have led to bans on usage and production in some countries.

8 Accumulations of heavy metals (e.g. mercury, copper) resulting from industrial outfalls may cause serious human health problems. Historically, the damaging effects caused by humans eating mercury-contaminated seafood were shown in the 1950s in Minamata, Japan, where more than 2000 people were directly affected. Now regulations and monitoring programmes exist to limit and detect unacceptable concentrations of these metals in marine products.

9 Sewage disposal is a major form of coastal pollution throughout the world. Nutrients in human wastes and those in detergents and fertilizers enrich local waters. This eutrophication may be beneficial in some cases, but often the amount of nutrients delivered leads to excessive plankton blooms that eventually decay and cause oxygen depletion. Pathogenic organisms in human wastes, like the cholera virus, can be filtered out of water near sewage outfalls by mussels and clams, and then be transmitted to humans who consume this seafood.

10 Radioactive wastes do not presently occur in concentrations that threaten marine life, although it is known that some organisms, particularly seaweeds and bivalves, can accumulate radionuclides from waters around nuclear plants.

11 Power plants release heated water that elevates ambient seawater temperature and thereby affects marine communities within the immediate area. In some cases the heated effluent is used to enhance growth rates of organisms grown in culture, but often the community changes are detrimental or unwanted.

12 Some marine communities and ecosystems have been changed through the deliberate or accidental transplantation of species. Increased commercial shipping has accelerated the rate of introduction of species into new environments, with an estimated 3000 species of marine plants and animals being carried daily across oceans in the ballast tanks of ships. Many do not survive but some, like the ctenophore *Mnemiopsis* or the zebra mussel, have major impacts on their new environments.

13 Estuaries and mangrove swamps are productive coastal ecosystems that constitute important spawning and nursery grounds for many fish, harbour shellfish populations, and provide rich feeding grounds for birds. As well, mangrove swamps buffer coastlines from erosion and inundation during tropical storms. However, these ecosystems are often heavily affected by human activities such as land reclamation, disposal of sewage and industrial wastes, and eutrophication.

14 Coral reefs are declining throughout the world. Expanding human populations near reefs and increasing tourism have accelerated development and have brought growing pressure to exploit reef resources. Coral reefs are detrimentally affected by increased sedimentation resulting from land development and subsequent erosion, and from eutrophication stemming from sewage disposal and agricultural runoff. In some locales, the coral is mined as building material. Destructive fishing techniques remove large numbers of fish, change species composition on the reef, and damage corals directly. Corals world-wide have been affected by elevations in seawater temperature, and global warming is a potential danger to reef communities.

Now try the following questions to consolidate your understanding of this Chapter.

QUESTION 9.5 The subject of human impacts on marine biota is much too large to cover fully in this chapter. What other impacts can you think of that might have been included?

QUESTION 9.6 Is it possible to harvest fish from the sea without causing changes in marine ecosystems?

QUESTION 9.7 Does sewage disposal at sea have any beneficial impact?

QUESTION 9.8 Estuary A receives freshwater with a high sediment load, whereas Estuary B receives relatively clear river water. Both receive approximately equal amounts of urban pollutants. Which estuary would have lower concentrations of these pollutants in the water, and which would have lower pollutant concentrations in the sediments?