Section I

Issues and mechanisms

A football-sized jellyfish (*Periphylla* spp.) under antarctic sea ice. McMurdo Sound, Southern Ocean. Photograph by the authors.

The two chapters in this Section document the many issues facing conservation and the many tools for dealing with them. Conservation issues relate specifically to biological issues (i.e., species depletions or habitat change), to issues that involve human activities (i.e., resource extractions and pollution), or to less apparent issues that affect ecosystem structure, function, and resiliency. Together these issues result in environmental change that is increasing in rate, magnitude, and duration, and from which recovery is difficult. Collectively, these issues contribute to an environmental debt, which is the total adjustment required to recover from change. The many current conservation and management mechanisms now in use overwhelmingly direct methods towards resolving specific issues, one by one. Although many successes are apparent, the environmental debt looms ever greater. Therefore, how can conservation mechanisms be made more effective to deal with the critical individual issues while confronting the mounting environmental debt?

Top: A healthy, high-diversity reef with corals, sponges, and gorgonians, Exuma Cays, Bahamas. Bottom: Turtlegrass (*Thalassia testudinum*) bed with a common sea star (*Oreaster reticulatus*) Cay Sal Bank, Bahamas. Photographs by the authors.

Chapter 1

Conservation issues

The materials of wealth are in the earth, on the seas, and in their natural and unaided productions.
Daniel Webster

It is time to understand "the environment" for what it is: the *national-security issue of the early twenty-first century.*
Robert D. Kaplan

1.1 Introduction

Three sets of issues compel recognition of forces that are global in scope, deepen the environmental debt, and raise ethical concerns about sustainability. Primary issues focus on species and their habitats and have long been the major focus of conservation. Secondary issues, conversely, direct attention toward human activities as causes for change. These activities have only relatively recently received conservation attention. However, the accelerating rates and momentum of human activities, and consequent ecosystem changes, have become high conservation priorities.

Efforts to address primary and secondary issues have slowed the depletion of life and its habitats, but have mostly failed to reverse trends of depletion and loss. This situation requires attention to systemic tertiary issues, involving emergent environmental phenomena, altered ecosystem states, and rates and dimensions of environmental and social change. Tertiary issues cause coastal-marine conservation to face complex, chronic problems that confound simple solutions.

1.2 Primary issues

Historically, most emphasis has been placed on depletion and extinction of species and protection of habitat. Yet, primary issues expand these domains to include species overabundance, ill-health, abnormal behaviors, and deteriorating habitats. Together, primary issues bring public attention to the need for conservation action.

1.2.1 Species extinction and depletion

Extinctions and depletions of coastal-marine species are documented worldwide and across most taxa (Table 1.1). Of the more than 120 species of marine mammals, at least a quarter is presently depleted and several are extinct. The Atlantic gray whale probably became extinct during the earliest days of Native American and European whaling. The Steller sea-cow population had probably already been decimated by subsistence hunters when it was discovered in 1741, and was hunted to extinction only 27 years later. The four remaining sea cows (one dugong and three manatees) are all endangered. The Caribbean monk seal was last reliably sighted in the 1950s near Jamaica. The Mediterranean monk seal population hovers around 300–400 individuals and the Hawaiian monk seal is also endangered. Large baleen whales seemed to be on the road to extinction until almost all whaling ceased in the 1980s; the North Atlantic right whale remains at risk. The Chinese river dolphin is critically endangered, as is the vaquita, a small porpoise endemic to the northeastern Gulf of California; both are among the world's rarest mammals. Sea birds and sea turtles have suffered similar fates. Most sea turtles are endangered. The Labrador duck and the flightless great auk became extinct in the 1800s, due to decimation by hunters for food, and many large sea birds, particularly albatrosses, are still being depleted.

Invertebrates and fishes are difficult to observe. The first documented extinction of a marine invertebrate was the North Atlantic eelgrass limpet, which disappeared in the early 1930s when a disease exterminated eelgrass beds, its sole habitat. The California white abalone existed in the thousands in the 1960s; now, the few remaining individuals are so widely separated that they may not be able to reproduce. Lately, fishes have elicited great public concern. Once abundant populations of cod, haddock, swordfish, salmons, tunas, sharks, and others have become severely depleted. The barndoor skate of the northwest Atlantic has been

Table 1.1 Selected extinct, endangered, and depleted species, illustrating worldwide depletion and extinction among a wide range of species groups.

Common name	Latin name	Range
Invertebrates		
Eelgrass limpet	*Lottia alveus*	North Atlantic
Rocky, mid-intertidal limpet	*"Collissella" edmitchell*	California (USA)
White abalone	*Haliotis sorenseni*	California (USA)
Fish		
Shortnose sturgeon	*Acipenser brevirostrum*	North Atlantic
Chinook salmon	*Oncorhynchus tshawytscha*	North Pacific
Totoaba (sea trout)	*Cynoscion macdonaldi*	Gulf of California
Barndoor skate	*Diptura laevis*	North Atlantic
Reptiles		
Green turtle	*Chelonia mydas*	Worldwide
Kemp's Ridley turtle	*Lepidochelys kempii*	Gulf of Mexico
Birds		
Auckland Island merganser	*Mergus australis*	New Zealand
Tahitian sandpiper	*Prosobonia leucoptera*	French Polynesia
New Providence hummingbird	*Chlorostilbon bracei*	Bahamas
Guadalupe storm petrel	*Oceanodroma macrodactyla*	Mexico
Bonin night heron	*Nycticorax caledonicus*	Japan
Steller's spectacled cormorant	*Phalacrocorax persipicillatus*	Komandorskiye Is. (Russia)
Canarian black oyster catcher	*Haematopus meadewaldoi*	Canary Islands (Spain)
Javanese wattled lapwing	*Vanellus macropterus*	Indonesia
Labrador duck	*Camptorhynchus labradorius*	North Atlantic
Great auk	*Pinguinus impennis*	North Atlantic
Short-tailed albatross	*Diomedea albatrus*	North Pacific
Cahow (Bermuda petrel)	*Pterodroma cahow*	North Atlantic
Mammals		
Steller sea cow	*Hydrodamalis gigas*	Komandorskiye Is. (Russia)
Caribbean monk seal	*Monachus tropicalis*	Caribbean Sea
Mediterranean monk seal	*Monachus monachus*	Mediterranean
Hawaiian monk seal	*Monachus schauinslandi*	Hawaiian Islands
Atlantic gray whale	*Eschrichtius robustus*	North Atlantic
Northern right whale	*Balaena glacialis*	North Atlantic
Chinese white flag dolphin	*Lipotes vexillifer*	Yangtze River
Vaquita porpoise	*Phocoena sinus*	Gulf of California
Marine otter	*Lutra felina*	South Pacific
Sea mink	*Mustela macrodon*	Nova Scotia to New England

Compiled from Carlton (1993); Norse (1993); Upton (1992); WCMC (1992).

drastically reduced due to by-catch in nets intended for other species. In the northern Gulf of California, the estuarine totoaba has become threatened by fishing, damming, and massive extraction of water from the Colorado River.

Coastal fishes that ascend or descend rivers and estuaries to spawn are especially vulnerable. Sturgeons, salmons, shad, menhaden, and others are widely depleted. Most sturgeons that inhabit fresh and coastal waters of Europe, Siberia, and North America are listed as threatened or endangered. The European sturgeon is one of the largest and most valuable of all fishes, and was common in the 1800s from the Baltic to the Black Sea. By the 1940s, spawning apparently occurred in only two rivers of western Europe. North American sturgeons have suffered similar fates. Many fishes that return to natal rivers to spawn, notably the "king" of salmons, the chinook, have been depleted or extirpated due to combinations of habitat alteration, pollution, and overfishing.

These few examples exemplify an issue of unknown dimensions. Many species remain to be discovered and many species, especially of smaller size and lesser economic importance, have no doubt disappeared without documentation of their existence. Data on population trends are especially sparse because original population numbers are not known.

1.2.2 Overabundance

Conversely to depletion, many species have recently flourished and become a concern when they dominate their communities, threaten human livelihood, depress densities of other species, deplete their own habitats, or cause a change in ecosystem function (Table 1.2). Overabundance is of greatest concern when native or introduced (exotic) species become invasive and do harm to other species or to their ecosystem. In areas of the Indo-Pacific, the native crown-of-thorns starfish recently became so numerous that it decimated coral reefs. The introduced American comb jelly, *Mnemiopsis*, has reduced plankton biomass and altered food webs of the Black and Azov seas. A fast-growing exotic alga, *Caulerpa*, is transforming portions of the Mediterranean seafloor into a dense, single-species cover, and has recently appeared in southern California and Australia. The invasive, native, common reed now dominates many U.S. wetlands (Box 1.1).

Box 1.1 A perspective on an overabundant invasive species: common reed, *Phragmites australis*

James E. Perry

An "invasive species" is defined as an alien species (i.e., any plant or animal species that is not native to that ecosystem) whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health (U.S. Presidential Executive Order 13112). While the term "native" implies that invasive species come from a foreign country or continent, it is important to note that this is not always the case. Given the dynamic nature of ecosystems and the propensity for humans to modify these habitats (such as filling or dredging of wetlands), we now know that some of our native species will become invasive if given the opportunity. The common reed, *Phragmites australis*, is one of these species. This vascular plant occurs in wetlands throughout the world. It is an aggressive colonizer of disturbed sites and exhibits rapid vegetative propagation (1–2 m yr^{-1}), and is capable of suppressing competitors by shading and litter mat formation, which gives the plant a distinct advantage over other species. Once established in a wetland, it is extremely difficult and expensive to eradicate.

Common reed has become a distinct problem in restored and/or created wetlands in the mid-Atlantic region of the United States. Because of the disturbance nature of wetland restoration and/or construction (earth removal and movement), newly constructed marshes are highly susceptible to common reed invasion. This species is considered undesirable by resource managers of this region partly because of its ability to replace the dominant species of numerous tidal and non-tidal wetland plant communities and, therefore, to reduce habitat diversity. On highway I-95 in New York–New Jersey just south of New York City, hundreds of acres of common reed have replaced a mixed community of salt, salt meadow hay, and tall cordgrass marshes. Common reed has become invasive through its ability to rapidly colonize disturbed, particularly human-disturbed, habitats. Thus, for every road crossing, every dredge-spoil sidecasting, and every parking lot next to a marsh, common reed has invaded into other marsh types, and has lowered the biodiversity of these important systems.

Attempts to limit or eradicate common reed have met with variable success. Small populations can be removed by pulling up plants, but this needs to be done before flowering to avoid dispersing seeds during removal. Application of herbicides can be effective, but care must be taken as these broad-spectrum herbicides can destroy adjacent desirable species. Most current use of herbicides is in conjunction with multiple burnings of the marsh. The financial cost of eradication is high. Herbicides themselves are expensive and spraying of large areas is done by helicopter. Some managers question these costs, particularly when one considers that eradication is usually temporary: in most cases the common reed will return from adjacent wetlands to repopulate the treated area. Salinity and flooding have also been shown to have adverse effects on common reed, and die-back has been reported at sites where soil salinity was higher than 15‰.

The questions common reed poses to wetland scientists, regulators, and managers are complex. Since wetland restoration and/or creation will continue in the mid-Atlantic United States, what role should common reed be allowed to play in future wetland plant communities? Can wetland restoration and/or creation be considered successful if these sites are quickly invaded by common reed?

Table 1.2 Examples of overabundance. Some are natives; others are exotics (E).

Organism/Origin	Location affected	Characteristic	Impact
Dinoflagellates (microflagellate) Worldwide	Coastal seas, worldwide	Red and brown blooms	Discolors water; may kill variety of species; produces shellfish toxins
Chrysophytes (micro-golden algae) Worldwide	Coastal seas, worldwide	Golden-brown blooms	Discolors water; shades aquatic plants; disrupts food webs; causes hypoxia
Diatoms Worldwide	Coastal seas, worldwide	Algal blooms	Sometimes lethal; mucus clogs fishing nets
Cyanobacteria (blue-green algae) Worldwide	Global ocean, coastal	Blue-green algal bloom	Range from harmless to toxic
Green alga *Caulerpa taxifolia* Aquaria	Mediterranean, California, Australia	Invasive macro-alga (E)	Threatens benthic community
Australian "pine" *Casuarina equisetifolia* India to Australia	Tropical islands and coasts, worldwide	Invasive tree on impoverished or disturbed soils (E)	Invasive; alters ecosystems; depletes biodiversity; causes erosion
Jelly *Aurelia aurita* Northwest Atlantic	Black Sea	Pelagic, plankton-feeder (E)	Nuisance; biomass ~450 million tons
American comb jelly *Mnemiopsis leidyi* Northwest Atlantic	Mediterranean, Black, Azov seas	Pelagic carnivore of plankton (E)	Threatens plankton biomass and fisheries
European green crab *Carcinus maenas* Northeast Atlantic	Northern California, Oregon	Voracious benthic invertebrate (E)	Threatens small shore crabs, native clams, near-shore invertebrates
Chinese clam *Potamocorbula* sp. Northwest Pacific	San Francisco, Northern California	Invasive benthic invertebrate (E)	Threatens benthic community
Indo-Pacific mussel *Perna perna* Tropical Pacific	Gulf of Mexico	Invasive filter-feeder (E)	Nuisance; beds extend for kilometers
Zebra mussel *Dreissena polymorpha* Europe	Baltic Sea, North America, Europe	Invasive freshwater filter-feeder (E)	Clogs pipes; eliminates benthic life; reduces plankton abundance
Crown-of-thorns starfish *Acanthaster planci* Indo-Pacific	Indo-Pacific	May suddenly increase in numbers	Consumes coral polyps; decimates reefs
Lionfish *Pterois volitans* Indo-Pacific	Northwest Atlantic	Introduced from aquaria (E)	Highly toxic, voracious carnivore
Snow goose *Chen caerulescens* North America	North American Arctic	Explosive overabundance	Degrades arctic nesting area
Gray seal *Halichoerus grypus* North Atlantic	North Sea	Abundant and protected	Said to deplete cod fisheries
California sea lion *Zalophus californianus* Northeast Pacific	Northeast Pacific	Increasing and protected	Consumes salmons; has become a "pest" on docks

Compiled from Carlton (1985); Duxbury & Duxbury (1997); Kenney et al. (1996); Pollard & Hutchings (1990a,b); NAS (1995); Raloff (1998); Schneider & Heinemann (1996); Sherman et al. (1996); Stephens et al. (1988); Steneck & Carlton (2001); Whitfield et al. (2002); Woodham (1997).

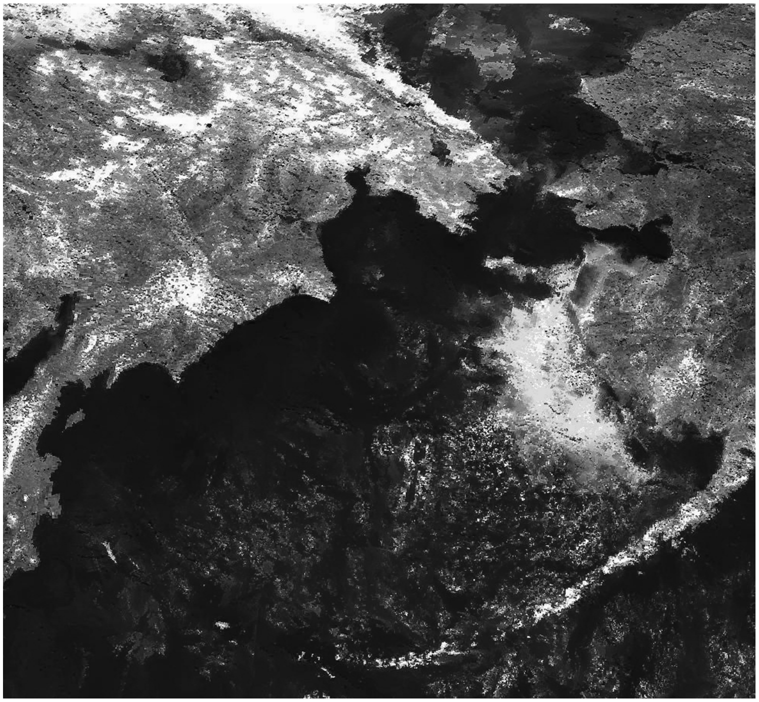

Fig. 1.1 Satellite image of the Bering Sea, September 1998. A plankton (coccolithophore) bloom is the light-shaded area, on right. Causes unknown; no deleterious effects discovered. Courtesy of Jacques Descloitres, NASA Goddard Space Flight Center.

Planktonic species are especially notable invaders, and often "bloom" in such massive numbers that they discolor the water, as "red tides" (dinoflagellates), "green films" (cyanobacteria), and "brown tides" (chrysophytes). Some blooms are localized in bays or estuaries; others cover thousands of square kilometers (Fig. 1.1). Blooms may last for weeks. Some occur at the same time and place each year; others occur unpredictably. Some are harmless; others kill marine life and produce noxious gases. Causes are often obscure; some occur in response to nutrient inputs.

Overabundance also occurs in aquatic birds and mammals. The snow goose has exploded in numbers and is causing extensive habitat damage in coastal breeding areas. Fishermen claim that overabundant seals deplete valuable fisheries: for example, gray seals that consume cod in the North Sea and California sea lions that consume salmons on North America's Pacific coast.

1.2.3 Ill-health

Ill-health focuses on abnormal physiological states and compromised immune systems, expressed as lesions, diseases, and deformities. These have been recorded for a wide variety of taxa, in epidemic proportions, regionwide, associated with pollution, as massive die-offs, or as individual strandings (Table 1.3). Ill-health brings into question what constitutes normalcy. Little is known about the "normal state" of health of most marine species. For example, in corals and their relatives, ill-health is described as "white line," "black line," and fungus diseases of uncertain etiology and taxonomy.

Many diseases are recently discovered. Farmed Atlantic salmon (*Salmo salar*) are susceptible to contagious infectious anemia. A tumor mass (fibropapillomatosis) caused by a virus is commonly observed in sea turtles. A brain disease (avian vacuolar myelinopathy) has inflicted coastal bald eagles and waterfowl in the southeastern United States. And in Scotland's northeast waters, more than 90% of a population of adult bottlenose dolphins (*Tursiops truncatus*) had epidermal lesions.

In polluted harbors and contaminated waters, ill-health takes many forms, including skeletal deformities, tumors, sores, fin rot, pathogenic viruses and bacteria, fungi, protozoans, and various invertebrate parasites. Pollution has also been shown to induce malformation and mortality, associated with abnormal embryonic chromosome division, for example in planktonic eggs

Table 1.3 Examples of ill-health.

Condition	Group(s) affected (Disease)	Location
Orange disease	Coralline algae: *Porolithon*	South Pacific
Abnormalities: shell/spine deformities, abnormal scales	Invertebrates; fishes	North Atlantic, Japan, South California
Moribund Withering Syndrome	Red abalone: *Haliotis*	South California
Lesions: skin, skull, brain, other organs. Pathogens mostly unidentified	Fishes (ulcerations, fin rot), marine mammals, birds	Baltic, North Sea, Southwest Atlantic
Fungal infections	Sea fans *Gorgonia ventalina*; corals, several; seagrass *Zostera marina* (wasting disease); fishes, herrings	North Atlantic, Florida, Central and South America, Caribbean
Tumors	Fishes; sea turtles (fibropapillomatosis)	Bays, harbors, coasts, banks, sounds, estuaries
Viral infections	Fish (lymphocystis) Birds (infectious bursal disease) Seals (phocine distemper) Sea otter *Enhydra lutris* (herpesvirus) Marine mammals (morbillivirus)	Worldwide; Northeast Pacific
Bacterial infections	Corals *Acropora palmata*: "white pox" (*Serratia marcescens*) Fish (hemorrhagic disease, fin rot, ulcerations, red sore)	Industrial-urban bays, harbors, coasts, reefs; Wider Caribbean
Protozoan infections	Oysters (dermo, MSX) Dolphins (fatal hepatic sarcocystosis)	Worldwide
Reproductive disorders	Fishes (defective eggs, larvae) Marine mammals (reproductive failure, aborted fetuses)	Baltic, North Sea, North Atlantic, North Pacific, Arctic

Compiled from Aguirre (1998); Cervino et al. (1998); Geiser et al. (1998); Littler & Littler (1995); Nagelkerken et al. (1997); Patterson et al. (2002); Raloff (1998); Reimer & Lipscomb (1998); Resendes et al. (2002); Sindermann (1996); Wilson et al. (2000).

of Atlantic mackerel (*Scomber scombrus*). Furthermore, some marine diseases are of human origin: a bacterial species of the human gut has recently been shown to be a pathogen of corals.

1.2.4 Abnormal behavior

Changes in distributions and behavior, such as altered times and places of breeding, have been observed in coastal-marine species in response to climate or to human-caused alterations of the land- or seascape. Most altered behaviors have been recorded for birds and mammals that are relatively easy to observe. Some waterfowl that normally feed on shallow-water vegetation now consume crop residues left on farms and may not migrate. Gulls have become nuisances around garbage dumps and fishing vessels. Gulls and sea lions follow fishing boats to feed on discarded offal. California sea lions become noisy nuisances when they haul out on docks. Florida manatees often avoid winter's cold by congregating in warm-water effluents of power plants. Some cetaceans hybridize, but whether this is abnormal is unknown.

Marine mammal strandings are of particular interest (Box 1.2). One cause may be avoidance of unfavorable water conditions, such as toxic algal blooms. Another cause may be noise generated by ships: commercial, recreational, and military uses of the seas all produce significant noise and have rapidly increased in recent years. Strandings almost always arouse great public attention and, nowadays, intense efforts are made to direct the animals back to sea or save them under veterinary care.

Attacks on humans may be abnormal, and causes for shark attack are speculative. Sharks have decreased in numbers recently; yet, shark attacks do not appear to be decreasing, possibly because of increased numbers of swimmers in nearshore waters. Occasional attacks by marine mammals on swimmers suggest responses to human harassment. On the other hand, some marine mammal interactions with humans are mutualistic, positive, and learned. The immortalized killer whale, "Old Tom" of Twofold Bay, Australia, guided Australian whalers to humpback whales in the early 1900s. Tom was rewarded with the tongue of the whale. Dolphins are also known to aid coastal fishermen in pursuit of

Box 1.2 Cetacean strandings

James G. Mead

The word "stranding" is derived from "strand" the shore of the sea. The word usually applies to a denizen of the marine environment that has come ashore, whether under its own volition or not. When whales and dolphins die they normally sink to the bottom. If the water is shallow, decomposition gases form in the tissues and the carcass floats and drifts ashore. In waters that are sufficiently deep, the gases remain in solution and the body decomposes on the bottom.

Single strandings represent individual mortality and are of interest only when they occur in unusual numbers. Mass strandings are events that involve a number of animals. Sometimes stranded animals do not have to be close together to constitute a mass stranding. A case in point is the stranding of short-finned pilot whales (*Globicephala macrorhynchus*) along the east and gulf coasts of the United States. From 1970 to 1980 the number of individuals averaged 1.8 per year (range 0–3). Suddenly, four strandings occurred in May 1973, scattered from Ocean City, New Jersey, to Bodie Island, North Carolina. This may be categorized as one mass stranding, extended in space. Any one of those would be classed as a single stranding, without information on the others. Baleen whales (mysticetes) have not been shown to be subject to the same mass strandings as toothed whales (odontocetes). A 1987–88 mortality of humpbacks, involving 14 individuals during 5 weeks and over about 300 km distance, could have been interpreted as a mass stranding. This event was, however, shown to be the result of paralytic shellfish poisoning.

Mass strandings have been occurring for millennia and have been subjects of speculation for almost as long. However, whether some events referred to in the literature are mass strandings or drive fisheries is problematic. Some of the largest strandings were false killer (*Pseudorca crassidens*) and long-finned pilot (*Globicephala melas*) whales. These strandings occurred in areas and at times when there was an active drive fishery (Japan and Massachusetts, respectively). The highest mortality recorded to date is 310 long-finned pilot whales that stranded in New Zealand in 1987.

Explanations of the causes of mass strandings are: confusion induced by coastal topography along shallow, sloping, sandy shorelines; errors in geomagnetic navigation; reversion to ancient migratory routes; pollution; ingestion of debris; chase or harassment; unusual underwater noises; sudden stress; shallow-water feeding; and diseases, parasites, neurological disorders, suicide, overpopulation, or getting blown ashore by storms. In 1987 and 1988 there was a spectacular increase in strandings of bottlenose dolphins (*Tursiops truncatus*) along the Atlantic coast of the United States. The mortality lasted from June 1987 to February 1988 and extended from New Jersey to Florida. Painstaking work by an army of investigators on those stranded animals determined that the mortality was due to morbillovirus infection.

Strandings provide scientists with an avenue for investigating cetaceans. The most basic information of all, the existence of a species, is frequently brought to light by strandings. Original descriptions of 20 out of 21 species of beaked whales (Family Ziphiidae) have been based on strandings. Strandings also contribute to the gradual assembly of life-history information, including feeding habits, reproduction, age, growth, and pathology. Ideas about the functional mechanisms that cetaceans have evolved may depend on comparative studies – for example, insights into thermoregulation of reproductive tissues. Recognizing pathologies depends on knowledge of the anatomical structure of "normal" animals. Strandings provide a way of monitoring adverse human interactions with cetaceans. Increased mortality due to fisheries interactions is frequently observed on stranded animals, for example subtle net marks. Stranded animals also provide a source of material for monitoring levels of anthropogenic contaminants (pollution) in marine systems.

fish, and reports of dolphins associating with people have become common.

Materials introduced by humans into the sea profoundly alter feeding behavior, for example when objects unfamiliar to sea life are ingested. Sea turtles, sea birds, and marine mammals are especially likely to ingest foreign objects, and each year many thousands may be injured, receive inadequate nutrition, or die because of this propensity. Additionally, sea birds, sea turtles, and large, pelagic fishes take longline fish hooks and many thousands die.

1.2.5 Deteriorating habitats

Interest in habitat extends to valued species, biodiversity, habitats created by living organisms (e.g., living reefs), and ecosystem functions. For thousands of years, coastal wetlands in China have been converted to rice production. In the conterminous United States, more than half of all coastal wetlands are degraded or have been converted. Globally, beds of aquatic vegetation have been decreasing, affecting the abundance of invertebrates and waterfowl. Since the 1960s, more than half of all tropical mangroves have been logged and replaced by croplands, shrimp ponds, and tourist resorts. Also, coral reefs are deteriorating globally as a result of bleaching, disease, and human disturbances. Temperate oyster reefs have been depleted even more intensively and for a longer period; those that remain are now vestiges of their former extents.

On a larger scale, bays, sounds, and estuaries have been dramatically affected by alteration of watershed flows, overfishing, pollution, and human occupation. Many productive coastal habitats are in critical states of deterioration and contamination, particularly in industrialized regions. A case in point is San Francisco Bay: during the past century and a half, approximately 60% of its area has disappeared under a massive sediment load released from upland mining and other forms of development. The Mississippi River has been physically changed by levées since the early 1800s; today, its delta region and the northern Gulf of Mexico are subject to nutrient enrichment, oxygen deficiencies, and depleted food webs. Similar changes have occurred in most of the world's major bays, rivers, and estuarine systems.

Islands and beaches are of special concern. On land, islands have experienced the world's highest extinction rates. Oceanic islands inspired Charles Darwin and Alfred Russel Wallace to formulate the Theory of Evolution in the mid-1800s. Islands are hotbeds of evolution and host a high degree of endemism; 12 m sunflowers, 250 kg tortoises, peculiar creatures such as marine iguanas, and many others occur nowhere else. The world's longest barrier-island/beach system occupies United States coasts from Maine to Texas. Many of its approximately 300 barrier islands are undergoing rapid change, affecting beach-nesting birds and sea turtles and the barriers' ability to protect nearshore environments from ocean forces. Islands are also notorious for the ease with which natural communities can be upset by exotic species and other disturbances. However, very little is known of extinction off island shores.

1.3 Secondary issues

Secondary issues focus on regulation of human activities and resolution of conflicts that are generated as people mass into the coastal realm. These issues draw attention to changes in which humans have, for centuries if not millennia, been foremost agents of alteration.

1.3.1 Extractions: removing natural resources

Human societies have long benefited from seemingly endless supplies of food, minerals, chemicals, industrial products, building materials, and energy extracted from coastal land and oceans. Even seawater is a significant resource, from which freshwater, salt, and power can be extracted. Extractions usually result in ecosystem adjustments.

1.3.1.1 Fisheries

Modern fishing is an analog of the ancient hunter–gatherer. Its history resembles a "slash-and-burn" activity, moving from resource to resource and from ocean to ocean, taking first the largest, most valuable, and easiest species to hunt, then the smallest, most abundant, and logistically more difficult. Commercial fishing is dominated by only a few nations, with Peru, Japan, Chile, China, and the United States being the leaders in terms of tons landed. Today, the number of fishermen worldwide approaches 20 million; 90% are small-scale fishers who may account for 25% of the global catch. Furthermore, the fisheries industry employs almost ten times more persons than fishermen, including processors, shippers, and marketers.

World marine and inland fisheries production trebled from 18 million metric tons (mts) in 1950 to more than 100 million mts by the turn of the century (Fig. 1.2), by which time nearly 70% of the world's

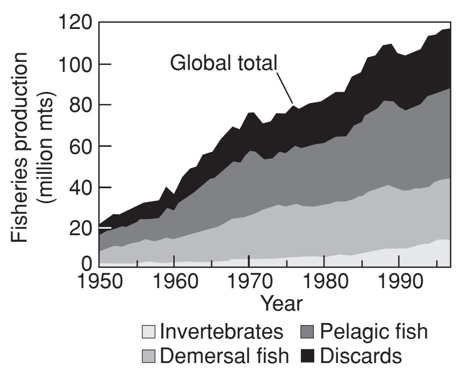

Fig. 1.2 Global fish catch has increased during the past half-century. Increasing catch of pelagic species is due mostly to increased catch of small species, while catch of demersal fish species has stagnated, and by-catch (mostly discarded) has increased. From Pauly et al. (2000), with permission from Sigma Xi.

marine commercial fish populations had become depleted. Today, few areas of the world remain unexploited. About 40% of the total catch enters an expanding market for human consumption. At least 20% is discarded as by-catch of non-target species. The remainder is divided among commercial and industrial uses, including pet food and fertilizer. As demand has increased, competition among fishers and the effort needed to catch a given weight of fish have increased, resulting in collapses of formerly flourishing fish populations. Technology also plays a significant role. Even small fishing vessels are equipped to pinpoint fishing grounds and to find fish. Therefore, despite collapses, new resources have been exploited and total landings have increased.

Whaling illustrates many aspects of commercial fishing. The most abundant and largest species of easiest access in coastal waters were hunted first, then depleted, and discovery of new populations followed. Intensive European whaling began in the 18th century for the right whale (*Eubalaena glacialis*) in the northeast Atlantic, where this species was soon extirpated. Later, New Englanders pursued right whales in the northwest Atlantic. Again, the whales were depleted; only a remnant population now remains, with dubious chances for recovery. In the 1820s, New Englanders took up whaling for sperm whales (*Physeter catodon*) for their valuable oil. At about the same time, bowheads (*Balaena mysticetus*) were pursued in the Bering Sea. Both species soon became depleted. Development of larger ships and better technology allowed whaling to expand to remote areas. The most lucrative whaling followed the late 19th-century development of fast ships equipped with harpoon guns that could navigate high-latitude, nutrient-rich seas where whales aggregated in summer to feed. Whaling soon became a major industry in the Southern Ocean surrounding Antarctica where whalers caught the speedy rorquals (*Balaenoptera* species) and humpbacks (*Megaptera novaeangliae*). Meanwhile, lucrative hunts were underway in other oceans. During World War II, global whaling was interrupted. The post-War period saw the most intensive whaling of all. The result has been that most populations of large whales have been reduced to remnant ones (Fig. 1.3). Today, only the little 6–10 m minke whale (*Balaenoptera acutorostrata*) is legally taken in the Southern Ocean and the North Atlantic.

Fishing reflects a similar history. A typical pattern is observed in the exploitation of temperate, schooling fishes in the North Atlantic. Herring (*Clupea harengus*),

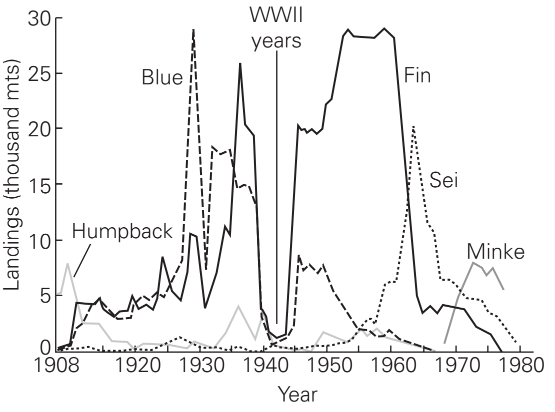

Fig. 1.3 Catch of baleen whales in the Southern Ocean from 1908 to the mid-1980s' moratorium established by the International Whaling Commission. Humpbacks were depleted first, then rorquals, in sequence from largest to smallest. From Jennings et al. (2001), with permission.

Atlantic cod (*Gadus morhua*), and others have supported European societies for many centuries (Fig. 1.4). Widespread depletions began in the 1800s. After World War II, increasing demand drove fisheries industries to exploit fishes more intensively. Depletions occurred first in the east, then in the west, and finally northward.

Today, fishing vessels are larger and more numerous than ever: in 1998, some 1124 fishing vessels greater than 100 tons were added to Lloyd's records. This increase in the fleet has been accompanied by major improvements in technology. Improvements in fish-finding devices and navigational aids have increased efficiency to the point that few fish schools go undetected. Trawl nets and seines have vastly increased in size, and towing two or more trawls can increase catch efficiency by 50–100%. Longlines with thousands of hooks may extend for tens of kilometers, and high seas drift nets can be more than 2 km long. All of these developments are highly efficient, but are non-selective and can result in greatly increased, unintended by-catch. Purse seines catch mammals and juvenile fish, and longlines and gillnets catch sharks, seabirds, and sea turtles. Furthermore, "ghost fishing" – the capture or entanglement of untargeted fish caught by discarded traps or nets at sea – results in considerable waste. Added to this are growing problems of illegal, unreported, and unregulated fishing that seem to be increasing worldwide. Finally, sport fishing is expanding and goes largely unrecorded, which substantially increases fisheries impacts and introduces uncertainty into management.

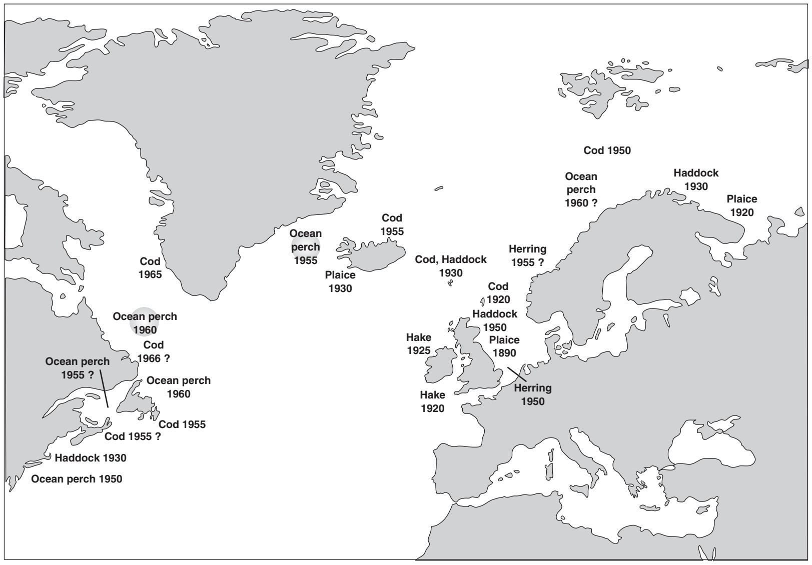

Fig. 1.4 Overfishing in the North Atlantic from before the 20th century. Plaice (*Pleuronectes platessa*) were depleted first in the North Sea; subsequently, fishing shifted to other areas, where the species was also depleted. The same sequence has occurred for other North Atlantic fisheries. Dates indicate approximately when increases in fishing effort no longer produced an increase in catch. From Holt (1969), with permission from Mr. N.H. Prentiss.

Table 1.4 Types of marine mineral resources.

Unconsolidated (within water)			Consolidated (packed, hardened)	
Dissolved	**Surficial**	**In place**	**Surficial**	**In place**
Metals, salts in fresh- and seawater: Magnesium, potassium, sodium, calcium, bromine, sulfur, strontium, boron, uranium, and many other elements	*Shallow beaches; offshore placers*: Sand, gravel; heavy minerals: iron, silica, lime *Deep ocean-floor deposits*: Red clays, calcareous ooze, siliceous ooze, metalliferous ooze *Authigenic deposits*: Manganese nodules (Co, Ni, Cu, Mn), phosphorite nodules, phosphorite sands, glauconite sands	*Buried and in river placers*: Diamonds, gold, platinum, tin *Heavy minerals*: Magnetite, ilmenite, rutile, zircon, leucoxene, monazite, chromite, scheelite, wolframite	*Exposed stratified deposits*: Coal, iron ore, limestone *Authigenic coatings*: Manganese oxide, associated Co, Ni, Cu, phosphorite	*Disseminated massive, vein or tabular deposits*: Coal, iron, tin, gold, sulfur, metallic sulfides, metallic salts

Modified from Mangone (1991).

1.3.1.2 Minerals

The coastal realm is a distinct geological province, where mineral resources of geological and biological origin occur in solution, on the sea-bed surface, or buried (Table 1.4). Salt, magnesium, and bromine are recovered from seawater. Rock, coral, calcareous marls, shells, sand, gravel, and lime are commonly removed from coastal areas. Mining of phosphorite for fertilizer often results in stripping salt marshes. Tin is taken from alluvial deposits on shores or beaches in Malaysia, Indonesia, Thailand, Australia, Nigeria, China, and other nations. Coal is removed from mines that have been tunneled out under the sea. And many high-value, low-volume minerals including platinum, gold, silver, titanium, zirconium, chromium, and rare-earth minerals are removed from shores. The extraction of almost all minerals produces considerable amounts of waste, much of it toxic.

The most valuable nonrenewable resource is petroleum. About a third of the global supply comes from the coastal realm. Exploration suggests that considerable amounts remain in offshore deposits, where risks of extraction are often great. Reserves in high-latitude seas are subject to sea ice, harsh storms in winter, and a propensity toward severe earthquakes, such as off Russia's eastern Sakhalin Island and in the Sea of Okhotsk where exploration has recently begun. In the tropics, hurricanes are a constant threat.

Most offshore oil exploration has, until recently, been in shallow, continental-shelf waters. Given the continuing demand for petroleum, drilling is occurring farther out to sea and under more hazardous conditions. Drilling is now able to penetrate as deep as 8500 m or more. The extraction of hydrocarbons has many costly consequences beyond simply affecting sea life: for example, economic risks, land subsidence, erosion, and saltwater intrusion into freshwater aquifers.

1.3.1.3 Carving up coastal substrates

Substrate disturbance includes mineral mining, wetland ditching for public-health concerns and conversion for development, bottom trawling for fisheries, and dredging canals and ports for shipping. All of these activities are accompanied by resuspension and deposition of sediment elsewhere. Also, dynamiting and cyanide poisoning of tropical reefs are common practices for extracting fish; thus, reefs and fisheries are destroyed and the natural protection that reefs provide to shores against erosion is removed.

Use of mobile fishing gear for dredging and trawling produces among the greatest of impacts on coastal-ocean ecosystems. The physical effects are comparable to forest clear-cutting, but are estimated to affect approximately 150 times more area globally (Table 1.5). The frequency of dredging is also much greater than forest clear-cutting: some productive fishing areas are completely dredged up to three or four times per year. Dredging and trawling increase turbidity, alter benthic habitat, crush, bury, and smother non-target, sessile species, and expose infauna to predation. Hydraulic dredging to extract shellfish is less extensive than trawling for fish, but can be even more damaging as it leaves a highly disturbed benthos and creates a sediment wake that trails as a plume for some distance before sediment settles to smother benthic plants and animals far downstream. Of possibly even greater significance is release and reburial of nutrients and toxic substances, and oxygen depletion.

1.3.2 Introductions and additives

Humans continually add innovative products to watersheds and to the ocean's chemical soup that can affect biogeochemistry and the biota. Introductions include synthetic chemicals, toxic metals, trash, radioactivity, pathogens, exotic species, and excessive heat, noise, and artificial light. These enter directly from pipelines or offshore dumping, and indirectly when storms drench the land to wash solids, nutrients, metals, pesticides, pathogens, and other contaminants from streets, pavements, lawns, and farmlands. Anthropogenic introductions may be added slowly and chronically or suddenly and in concentrated forms, but rarely in accord with natural rhythms. Long-lasting carcinogenic, toxic, or lethal chemicals and metals collect into a contaminant profile when they accumulate within sediments.

Introductions originate mostly from the land. Many countries use the seas as dumps for land-based wastes and many nations and cities continue to dispose of untreated sewage directly into coastal waters. Even in developed, industrial nations, municipal sewage and toxic industrial wastes have been widely discharged directly into rivers and estuaries. Introductions also originate at sea. Ships increasingly collide with sea life, and substances that affect sea life are added through accidental (oil spills), and deliberate and routine operations (ocean dumping, bilge cleaning, antifouling paints). Equipment used in diverse ocean operations (fishing, monitoring instruments, submarines, submersibles, cables, military hardware, munitions, etc.) is often lost or discarded at sea. Occasionally, these introductions provide habitat opportunities for sea life (wrecks, artificial reefs, and floating materials that attract a variety of species).

Finally, introductions enter from the sky. Storms, winds, and rain transfer dust, plastics, debris, trash, nutrients, and microbes globally. Wind transports aerosols containing pollutants and nutrients, which fall with precipitation. Incomplete combustion from fossil fuel industries and automobiles releases metals and toxic chemicals to the air. Industrial plants introduce nitrogen and sulfur compounds that affect atmospheric chemistry, as is implicated in "acid rain". Radioactive materials released into the atmosphere from nuclear

Table 1.5 Comparison of forest clearcutting and trawling impacts.

Impact on:	Forest clear-cutting	Bottom trawling/dredging by fishing gear
Substrate	Exposes soils to erosion; compresses soils	Overturns, moves, and buries boulders and cobbles; homogenizes sediments; eliminates existing microtopography; leaves long-lasting grooves
Roots and infauna	Saprotrophs (that decay roots) are stimulated then eliminated	Infauna crushed and buried; others become susceptible to scavenging
Biogenic structures	Removes above-ground logs; buries structure-forming species	Removes, damages, or displaces structure-forming species
Associated species	Eliminates most late-succession species; encourages pioneer species	Eliminates most late-succession species; encourages pioneer species
Biogeochemistry	Releases large pulse of carbon to atmosphere by removing and oxidizing accumulated organic material; eliminates arboreal lichens that fix nitrogen	Releases large pulse of carbon to water column and atmosphere by removing and oxidizing accumulated organic material; increases oxygen demand
Recovery time to original structure	Decades to centuries	Years to centuries
Typical return time	40–200 years	40 days to 10 years
Global area affected per year	~ 0.1 million km^2 of net forest and woodland loss	~ 14.8 million km^2
Latitudinal range	Subpolar to tropical	Subpolar to tropical
Ownership	Private and public	Public
Scientific documentation (publications)	Many	Few
Public awareness	Substantial	Very little
Legal status	Modification of activity to lessen impacts and to prohibit or favor alternative logging methods and preservation	Activity restricted in only a few areas

From Watling & Norse (1998), with permission.

power plants and nuclear weapons testing, especially during the 1940s to 1960s, persist in some areas today.

1.3.2.1 Petroleum and related by-products

"Petroleum" is a broad term that describes naturally occurring and refined compounds and natural gases. Petroleum enters the coastal ocean from natural and anthropogenic sources, including submarine seeps, tanker accidents, deballasting operations, tank washing, refinery effluents, municipal and industrial discharges, losses from pipelines, offshore production, and industrial, municipal, urban, and river runoff. The United States National Research Council (NRC 2002) estimated that approximately 1.4 billion liters of petroleum and related hydrocarbons enter the oceans annually, chronically in low doses or catastrophically in high doses. A city of five million people might annually release roughly the equivalent of oil spilled when the tanker *Exxon Valdez* struck Bligh Reef in Prince William Sound, Alaska in 1989 and released approximately 37 000 tons of crude oil that spread more than 900 km from the spill site. This spill left an estimated 12% of its oil on subtidal sediments, affecting many species, some of which have apparently not yet recovered. The difference is that a city's input is chronic and an oil spill at sea is acute.

Oil spills can occur unpredictably at any time (Table 1.6). The effects are as varied as the contaminants themselves. Spills are most harmful in shallow, low-energy aquatic environments, sediments, wetlands, tidal flats, and sites with abundant wildlife. Relatively non-toxic petroleum tars that wash onto coastlines and beaches can smother biota and cripple recreation and tourism. Spills also result in oiling of birds, marine mammals, shorelines, and sediment, and release toxic substances that can affect marine life. The effects can be long-lasting or fleeting, depending on environmental conditions and the nature of the spill itself. The effects of spills are becoming fairly well known. However, little is known about how diffuse, chronic releases affect marine systems.

Table 1.6 Examples of major oil spills.

Location	Source	Amount	Cause	Date
Persian Gulf	Iraq bombing	~ 130 000 000 gal.	War	1991
Gulf of Mexico	Ixtoc I oil well	~ 600 000 mt	Blowout	1983
Nantucket, Massachusetts	*Argo Merchant*	7 700 000 gal.	Grounding	1976
Brittany, France	*Amoco Cadiz*	223 000 mt	Grounding	1978
Scilly Isles, U.K.	*Torrey Canyon*	119 000 mt	Grounding	1972
Prince William Sound, Alaska	*Exxon Valdez*	37 000 mt	Grounding	1989
Angola, 700 mi offshore	*ATB Summer*	260 000 mt	Fire/explosion	1991
West Delta, Louisiana	Pipeline break	6 720 000 gal.	Dragging anchor	1967
Russian Arctic	*Usinsk*	4 300 000 gal.	Pipeline rupture	1994
Galapagos Islands	*Jessica*	240 000 gal.	Fueling luxury ecotourism liner	2001
Brazil	Oil platform	~ 400 000 gal.	Explosion	2001
Spain, Galicia coast	Bahamian oil tanker *The Prestige*	77 000 mt	Crack in single hull of aging fuel tanker	2002

Compiled from Button (2003); Clark (1997); Irwin et al. (1997); Montevecchi & Kerry (2001); World Almanac Books (1998).

1.3.2.2 Industrial chemicals and metals

Industrial chemicals and metals are especially serious contaminants because of their toxicity, ubiquity, and varied effects (Table 1.7). Tens of thousands of chemical compounds are used as pesticides, defoliants, chlorinated solvents, and other industrial products; many result unintentionally in serious side-effects for life. Methyl mercury causes severe neurological effects and developmental problems; it is widespread and quickly enters aquatic food webs. Antifouling paints are used on ships and docks to inhibit fouling by marine organisms. Tributyltin (TBT), in particular, has saved ship owners and dock operators hundreds of millions of dollars, but is lethal to marine life, especially shellfish larvae; its use is now widely prohibited.

Some components of refined petroleum are highly toxic. Polynuclear aromatic hydrocarbons (PAHs) are ubiquitous; they are formed from incomplete combustion, released to the air, transported in particulates, and precipitated to the sea surface. Sources include creosote on dock pilings, industrial effluents, domestic sewage, oil spills, and bilge water. High-molecular-weight PAHs pose potential hazards to humans and sea life. Chronic exposure of bottom-dwelling fish to PAHs can produce lesions and deformities. The more persistent, heavier (4-, 5-, and 6-ring as opposed to lighter 2- and 3-ring) PAHs tend to have greater carcinogenic potential; benzo(a)pyrene, a high-molecular-weight, 5-ring PAH, is a carcinogen that can concentrate in organisms, especially shellfish.

Many synthetic compounds and pesticides used in households, on farms, and in industrial and military operations are hazardous wastes that persist in aquatic environments. Halogenated aromatic hydrocarbons, including organochlorines, are among the most important. DDT (dichloro-diphenyl-trichloroethane) and its derivatives, DDE (dichloro-diphenyl-ethane) and DDD (dichloro-diphenyl-dichloroethane), are highly toxic and can affect immune-system function. Organophosphates and carbamates are less persistent, but highly toxic, especially to aquatic life. PCBs (polychlorinated biphenyls) are derived from plastics and electrical equipment, can be stored in sediments, and can cause tumors, fetal death, and birth defects. Dioxins comprise a group of extremely toxic and persistent synthetic organic chemicals. Currently, their major source is incineration. Dioxins can cause abnormalities and tumors. These and a host of other chemicals and heavy metals enter the oceans, get incorporated into benthic sediments and fat tissues of animals, and are passed up food chains.

National legislation and international agreements now prohibit dumping hazardous wastes at sea. However, these wastes may persist in "hot spots," especially in sediments of industrial ports. The impact of dredging ever-deeper channels to accommodate shipping is a paramount cause for release of toxic chemicals from sediment. Millions of tons of contaminated dredged material have been dumped into harbors and seas, where sediments still contain mixtures of toxic contaminants that can be released by dredging and bottom stirring. For emerging industrial nations, these problems are especially serious, as these nations may not have the capacity to deal with contaminated sediments.

Table 1.7 Some major, ubiquitous, toxic industrial contaminants, their source and their impact.

Pollutant type	Industrial source	Biological impact
Heavy metals		Interact with biomolecules; impact varies with species and organ; liver is great accumulator
Cadmium	Mines, rivers, atmosphere, dredging	Collects in inshore mudflats, bacterial films, and organic matter, which modifies toxic exposure to benthic organisms
Copper	Electrical industry alloys and electrical wiring, algicides, acid mine drainage	Essential in biochemical processes; catalyst in hemoglobin formation; highly toxic to invertebrates
Mercury	Pulp and paper mills, fungicides, fossil fuel combustion, mercurial catalysts, weathering	Natural bacteria convert mercury to methylmercury that concentrates in fish, which can be toxic if eaten
Tin	Organotin production for pesticides, PVC stabilizer, biocide, etc. increased from 5000 tons in 1985 to 35 000 tons in 1995; now ~50 000 tons	Damages marine life worldwide. Tributyltin is extremely toxic to oysters. Sediment microorganisms convert metallic tin into methyltin
Zinc	Alloys, paints, cosmetics, etc.: used to coat steel against corrosion	Catalytic activity in essential biochemical processes
Synthetic organic compounds		Many are lipophilic. Can be carcinogenic, mutagenic, endocrine disrupters
Organochlorines: DDT, DDE, DDD, chlordane, Kepone®	Pesticides extensively used since 1940s	Remain decades in sediment: lipophilic, concentrate in liver, bioaccumulate, hormonally active
Organophosphates: diazinon, malathion	Pesticides	Fish liver neurotoxin after intracell biotransformation; repeated exposure may damage neuroendocrine function
Carbamates: atrazine, sevin	Agriculture, crop herbicides	Highly toxic; rapidly detoxified from animal tissues and eliminated
Polynuclear aromatic hydrocarbons (PAHs)	Crude oil, refined oil, related aerosols	Low solubility in water, remain in sediment, biomagnify: benzo(a)pyrene is a carcinogen and endocrine disrupter
Polychlorinated biphenyls (PCBs)	Dielectric fluids in electrical equipment (transformers, hydraulic systems)	Highly persistent; sequester in sediments; concentrate in liver and gonad tissue
Dioxins	Combustion and incineration, pulp and paper production	Among the most toxic: occur in seafood; affect food webs, carcinogenic, endocrine disrupters

Compiled from Calmano & Förstner (1996); Kline (1998); NRC (1999).

1.3.2.3 Litter and plastics

Most litter is accidentally or carelessly released. However, many commercial, fishing, and military disposal operations purposefully introduce tens of thousands of tons of litter annually into the seas. Plastics are a dominant component of litter and their durability has made them a major environmental problem. Plastic litter ranges in size from particles a few millimeters in diameter to large objects. The amount of plastic entering the sea from all sources is not known, but casual observation of littered beaches indicates that it is massive (Fig. 7.14B, page 224). Even in isolated areas such as the deep sea, trawls retrieve plastics and other debris. Plastics resist degradation, and many can persist for decades to centuries. When they accumulate on shores, at sea, or on the ocean floor they become a public disgrace, especially when mixed with medical wastes.

The harm that plastics cause marine life is often obvious, but difficult to quantify (Table 1.8). Each year, an unknown number of sea turtles, birds, and marine mammals suffer malnourishment or die after swallowing plastics. Also, thousands are crippled or killed by entanglement, entrapment, smothering, and strangulation due to encounters with foreign objects, especially discarded fishing gear (Fig. 1.5). Floating plastic sheets may also cling to plants, corals, and tidal animals and smother them. And tens of thousands of fish traps made entirely or partially of plastic are lost at sea annually, many of which continue to "ghost fish" for long periods of time.

Table 1.8 The impact of plastics on biota.

Species group	Total number of species worldwide	Number (%) of species with entanglement records	Number (%) of species with ingestion records
Sea turtles	7	6 (86%)	6 (86%)
Sea birds	312	51 (16%)	111 (36%)
Sphenisciformes (penguins)	16	6 (38%)	1 (6%)
Podicipediformes (grebes)	19	2 (10%)	0 (0%)
Procellarfiformes (albatrosses, petrels, shearwaters)	99	10 (10%)	62 (63%)
Pelicaniformes (pelicans, boobies, gannets, cormorants, frigate birds, tropic birds)	51	11 (22%)	8 (16%)
Charadriiformes (shorebirds, skuas, gulls, terns, auks)	122	22 (18%)	40 (33%)
Other birds	–	5	0
Marine mammals	115	32 (28%)	26 (23%)
Mysticeti (baleen whales)	10	6 (60%)	2 (20%)
Odontoceti (toothed whales)	65	5 (8%)	21 (32%)
Otariidae (fur seals, sea lions)	14	11 (79%)	1 (7%)
Phocidae (true seals)	19	8 (42%)	1 (5%)
Sirenia (manatees, dugongs)	4	1 (25%)	1 (25%
Mustellidae (sea otter)	1	1 (100%)	0 (0%)
Fish	–	34	33
Crustaceans	–	8	0
Squid	–	0	1
Species total	–	**136**	**177**

Compiled from Laist (1996); Marine Mammal Commission (1995).

Fig. 1.5 Dead Steller sea lion (*Eumetopias jubatus*) entangled in discarded fishing gear, Amak Island, southeastern Bering Sea, 1974. The skeleton shows signs of having been consumed by a predator, probably a grizzly bear. Photograph by the authors.

1.3.2.4 Biological pollution and exotic species

Marine biological pollution includes pathogens and microbes, and exotic, transgenic, and invasive species. Introduction of exotic species into new locations now occurs on a regular basis and some invasive species have become extremely abundant. A serious problem concerns ship ballast water, which is responsible for many problem species and their often-severe economic consequences: for example, a Japanese toxic dinoflagellate (*Gymnodimium catenatum*) introduced into Australian waters, the zebra mussel and European shore crab to North America, and the comb jelly to the Black Sea (Table 1.2). Pathogens, such as the cholera bacterium (*Vibrio cholerae*), may enter marine environments accidentally when ships pump their bilges. Microorganisms are also introduced into marine waters with wastewater from septic systems, sewer overflows, and untreated sewage. To avoid pathogenic introductions, bilge water can be pumped into holding tanks at ports for treatment. However, treatment is expensive, monitoring is difficult, violations of the few regulations that do exist are frequent, and most ports have few, if any, facilities.

Introductions often bring changes to the biological communities that they have invaded. A recent example is the discovery of a population of Indo-Pacific lionfish in subtropical waters of the U.S. east coast, probably

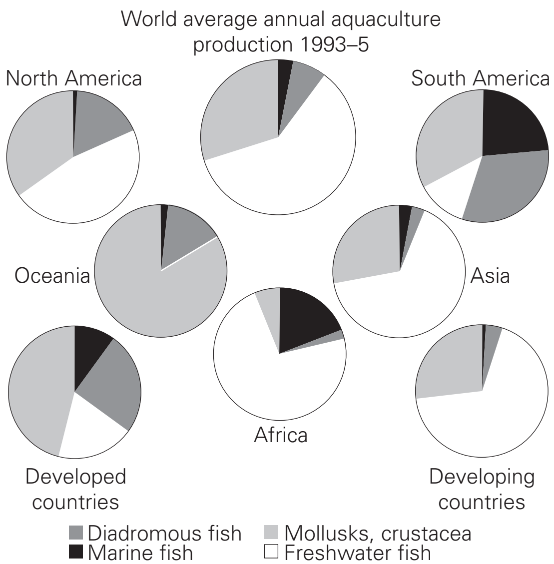

Fig. 1.6 Global aquaculture. Relative production by region and resource. Percentages are total average annual aquaculture production. Adapted from FAO (1995, 2001); WRI et al. (1998).

from an aquarium holding facility. This is the first known case of a successful introduction of a tropical Pacific fish into the northwest Atlantic. This attractive fish is a voracious predator that also bears highly venomous spines. In both appearance and predatory behavior, it is unique to the Atlantic and thus could be especially damaging to native prey species.

Aquaculture is a rapidly expanding source of biotic pollution. This activity is the raising of fishes, mollusks, crustaceans, and plants under confined, artificial conditions. Aquaculture is a very old practice that supplies much-needed food for many people, and has become a major global industry (Fig. 1.6). Brackish and saltwater aquaculture centers on a few species that are important export products and that attract high prices: for example, Atlantic (*Salmo salar*) and Pacific (*Onchorhynchus* species) salmons, and the marine fish called "dolphin" (or "mahi-mahi," *Coryphaena hippurus*). Aquaculture production systems differ widely, but most have four aspects in common. First, aquaculture depends heavily on natural sources of fishmeal and larvae for culture. Second, aquaculture usually requires conversion of natural habitat, such as estuaries, mangroves, and lagoons, into large ponds. Third, escaped individuals from aquacultural facilities may affect natural populations and communities through interbreeding, competition, and introduced diseases. The use of genetically engineered (transgenic) organisms is of special concern due to unknown interactions between farm-raised and naturally occurring populations. Farmed Atlantic salmon have escaped into Norwegian and North Pacific waters, with uncertain consequences for native fish populations. There is a long history of transfers of oysters into foreign waters. The Japanese oyster (*Crassostrea gigas*) is now farmed in North America, Europe, Australia, and elsewhere. To prevent interbreeding and replacement of native species, this species has been genetically altered so that it is presumably unable to reproduce; however, evidence indicates it can revert to breeding condition. Finally, aquaculture can become a source of pollution and disease. The crowding of individuals in restricted facilities creates ideal conditions for epidemics; antibiotics are used as preventatives. Thus, aquaculture generates large quantities of nutrients, pesticides, and antibiotics that can enter coastal waters, raising concerns about contamination and alteration of biochemical regimes.

1.3.2.5 Noise, heat, and light

Supertankers, huge fish-factory ships, cruise ships, and submersibles that explore the deepest parts of oceans create a noisy presence. Low-frequency sound is used for exploration of the ocean bottom for minerals and scientific measurement of water mass characteristics, and high- and low-frequency sounds are used in antisubmarine acoustic operations. All of these noises potentially can affect crustaceans, fishes, and marine mammals that use sound for underwater communication, food-finding, or navigation. Underwater noise has considerable potential to alter behavior or even to induce tissue damage if used intensively (Box 1.3).

Large amounts of heated water, often more than 10°C above ambient sea temperature, are introduced from power plants and other industrial activities into local waters. Heat can differentially affect local distributions and reproductive behavior of plants and animals. Elevated temperatures reduce oxygen supply and can exacerbate hypoxia. At levels above the physiological tolerance of a species, heated water can be lethal, notably in tropical corals that are sensitive to temperatures greater than 30°C.

Finally, artificial light from seaside development is a concern, especially for sea turtles, which return from the sea at night to nest on sandy shores – often where people prefer to recreate and live. Where urban lights add glow to dark shorelines, sea turtle hatchlings may

Box 1.3 Noise pollution: a threat to dolphins?

Sam Ridgway

The significance of human-made sound in disturbing or injuring cetaceans has been considered only recently. Earlier studies of dolphin hearing were motivated by the discovery of the animal's sonar. Audiograms, plots of hearing threshold at different sound frequencies (in Hz, cycles per second, or kHz; 1 kHz is equal to 1000 cycles of a sound wave), have been done on several species of the cetacean superfamily Delphinoidea (narwhals, white whales, all dolphins, and the porpoises). These audiograms showed sensitivity to sound frequencies up to about 60 to 150 kHz, almost eight times the frequency span of human hearing (humans are slightly more sensitive to sound pressure in air, but their frequency range is limited to about 20 kHz). In the frequency range of 40–80 kHz the bottlenose dolphin ear can sense a sound wave with a pressure of only 100 μPa (the pascal [Pa] is the standard measure of pressure, and a micropascal [μPa] is one millionth of a pascal). The ear is a phenomenal detector of pressure change. As a dolphin dives to a depth of 100 m the surrounding pressure is 1 trillion μPa yet the ear senses a pressure change one billionth the sea pressure. The dolphin ear can sense and respond to sounds as faint as 100 μPa and as loud as 10 billion μPa. Since these numbers are so large they become cumbersome to quantify, hearing is normally measured on a logarithmic decibel scale and related to a base value. For example, a dolphin threshold of 100 μPa is given as 40 dB re 1 μPa. A very loud sound that might overload the ear if it were continued for a second or more might be given as 200 dB re 1 μPa.

Sensitive ears connected to a massive auditory central nervous system are fundamental to the dolphin's echolocation and communication. It is reasonable to ask how an animal, with such excellent hearing, avoids damaging its own ears with the loud sounds it produces during echolocation. The dolphin ear, anatomically only a few centimeters away from its sound production mechanism, processes high-frequency echolocation pulses up to 230 dB re 1 μPa in peak to peak amplitude. Using intense pulses and sensitive ears, dolphins can detect echoes (as quiet as a human whisper) from small objects at 100 m and more. Because the dolphin's pulses are very brief, on the order of 40 μs (25 000 of these would equal a second of sound), the total energy within each pulse is miniscule. Anatomical structures, including highly reflective air sinuses that attenuate sound, probably help the animal avoid damaging its own ears.

On a comparative basis, the baleen whale auditory system does not appear as specialized as that of dolphins. The acoustic centers of the baleen whale brain are smaller than those of dolphins, for whom the auditory nerve is the largest cranial nerve; in baleen whales, the trigeminal nerve is larger. Unlike dolphins, whose sense of hearing predominates, baleen whales appear to rely most on the sense of touch. Although we have made no audiograms, observations show that baleen whales usually produce low-frequency sounds, often as low as 15 Hz.

If, as anatomical study suggests, the baleen whale ear is specialized for low frequencies, then the inference is that the animal's hearing is adapted to protection from considerable acoustic interference such as that which occurs from natural ocean background noise in the part of the acoustic spectrum below 1000 Hz. It is unlikely that baleen whales will be captured and trained for audiograms as have dolphins; nonetheless, physiological methods could be used to obtain audiograms on beached or entrapped whales.

The question arises: Can baleen whales detect calls of other whales by means other than auditory ones? The arrays of vibrissae about their heads suggest that baleen whales may use these adaptations to sense low-frequency vibrations including the calls of other baleen whales. Uses of tactile detection like these may explain the large trigeminal nerve in baleen whales. Until audiograms can be measured on baleen whales, we are left to speculate about their hearing thresholds and frequency sensitivities. The absence of definitive audiograms compounds the problem of determining what levels of human-generated sound may damage baleen whale hearing.

Dolphins have evolved robust mechanisms to protect their ears and body tissues from loud natural sounds such as lightning strikes, earthquakes, pounding surf, volcanic eruptions, whale calls, and even their own echolocation pulses. Year after year, these adaptations are eroded as oceanic shipping raises the ambient background noise in the oceans. These animals should not be continuously exposed to the equivalent of a boiler factory or even a loud discotheque. Intensified technology introduces loud noise for purposes of improved sonar, oil exploration, and acoustic communication modems. Increasing production of intrusive noise in the sea poses a serious threat to marine life. Science and technology must take action together in order to protect marine mammals such as dolphins and whales from dangerous noise.

Source: Popper et al. (2000).

become disoriented when they emerge from nests in the sand to scurry to the sea to avoid predators.

1.3.3 Physical alterations

Humans constitute a massive geophysical force as they transform the coastal and ocean horizon. Impervious substrates are replacing marshes and forests, urban centers are being joined into coastal conurbations, and a large portion of the land- and seascape now exists as patches of nature among areas of intense human use. Thus, the coastal land–seascape is being increasingly urbanized, compromising the natural flows and interchanges of coastal ecosystems (Table 1.9).

1.3.3.1 Reclamation and offshore development

Reclamation of coastal lands, water, and wetlands probably originated with the advent of the Agricultural Revolution 5000–10 000 years ago, and was greatly enhanced by establishment of coastal city-states. Salt marshes of England's Wash began to be reclaimed around AD 900 and only half remain intact today. In the Netherlands, great portions of the Zuidersea have been closed off and drained for agriculture. High dikes now prevent saltwater from intruding into agricultural land, and brackish lakes (polders) dominate large portions of the country; without this line of defense, the sea would threaten more than half of the Dutch population. Along Japan's coasts, where land is in short supply, man-made islands are being created to extend human occupation, industrial growth, and farming. A similar example is Hong Kong, where a large percent of coastal land is altered and former mangrove and saltmarsh environments have been converted for food production. In southeast Asia and Central and South America, large areas of coastal lowlands, particularly mangroves, have been converted to shrimp farms. Use of fertilizers and chemicals by farms and aquaculture increase pollution and eutrophy of coastal waters.

Table 1.9 Percents of coastline bordered by artificial structures.

Region	%	Region	%
Belgium	85	Scotland	8
Lake Erie, USA	61	Sweden	7
Japan	51	Portugal	7
South Carolina, USA	39	Oregon, USA	6
England	38	Ireland	< 5
Kuwait	29	Victoria, Canada	4
Barbados	22	Montserrat	3
Lake Erie, Canada	21	Finland	< 2
South Korea	21	Iceland	< 2
Italy	13	Brazil	1
California, USA	9	Sierra Leone	< 1
South Africa	9	Alaska, USA	< 1

Modified from Walker (1990).

Reclamation is most obvious in estuaries and lagoons with prime port locations and where many of the world's largest cities are located (Table 1.10). Gigantic petrochemical complexes, steel mills, power plants, condominiums, and ship-building facilities occur on or adjacent to some of the richest farmlands and fishery areas on Earth. Offshore, structures are built to accommodate oil and gas extraction from fixed platforms, particularly where navigational requirements for free passage of ships can be met and where undersea pipelines can be constructed. To support these facilities, onshore facilities must be constructed, such as platform fabrication yards with boats to carry supplies and equipment to rigs and platforms, helicopters to ferry personnel to and from offshore sites, and barges to install pipelines between production and processing facilities. Conflicts arise where fisheries also exist. The full impact of such development on future fisheries is difficult to predict.

Military activities contribute directly and indirectly to coastal transformations. In many areas, military reservations that are "off-limits" may host some of the best-preserved natural habitats. However, areas of armed conflict can severely disrupt coastal systems. The use of defoliants by U.S. forces in Vietnam destroyed 14% of Vietnam's forests and severely damaged economically important mangrove swamp ecosystems, while also adding hazardous toxics to both land and sea. During the 1990 Persian–Arabian Gulf conflict, an estimated 3–6 million barrels of oil per day were deliberately burned, and oil spilled into the waters of the Gulf severely damaged coastal land and marine ecosystems.

1.3.3.2 Obstructing watershed flows

Freshwater is required for every aspect of life. However, freshwater distribution is uneven, a situation that has initiated extensive dam and channel construction to regulate and divert water supply to places where it may be used. The majority of large watersheds worldwide have been modified by dam construction. Great dams have been constructed across major rivers to produce energy, to mitigate against destructive floods and droughts, and to provide water to farms and cities.

Table 1.10 Some of the world's largest cities and major ports (•).

City/country	Population, × 1000	Population, × 1000 (projected)	Annual growth rate (%)	Coastal water	Port, maximum draft (m)
	1995	2015	1995–99		
Tokyo, Japan•	26 959	28 887	1.45	Tokyo Bay	10.5
Mexico City, Mexico	16 562	19 180	1.81		
São Paulo, Brazil	16 533	20 320	1.84		
New York City, USA •	16 332	17 602	0.34	New York Bight	13.5
Bombay (Mumbai), India	15 138	26 218	4.24	Arabian Sea	
Shanghai, China •	13 584	17 969	0.36	East China Sea	10.0
Los Angeles, USA •	12 410	14 217	1.60	Complex units	21.4
Calcutta, India •	11 923	17 305	1.81	Bay of Bengal	
Buenos Aires, Argentina •	11 802	13 856	1.15	Rio de la Plata	
Seoul, South Korea	11 609	12 980	1.92	Yellow Sea	
Beijing, China	11 299	15 572	0.87	Bohai Sea	
Osaka, Japan •	10 609	10 609	0.23	Osaka Bay	11.5
Lagos, Nigeria	10 287	24 640	5.68	Bight of Benin	
Rio de Janeiro, Brazil •	10 181	11 860	1.00	Guanabara Bay	10.1
Delhi, India	9 948	16 860	3.85		

Modified from World Almanac (1999).

Reservoirs behind dams also serve as valuable recreation assets. During the major dam-building period between 1950 and the mid-1980s, the number of large dams increased seven-fold worldwide. In 1997, an estimated 800 000 large dams existed, of which 45 000 are higher than a five-story building (Fig. 1.7).

Dams can affect very large portions of watersheds and landscapes. There are six dams on the highly industrialized Rhine watershed, which crosses seven countries and encompasses 68 large cities before it drains into the North Sea. The longest river in the world, the Nile, embraces more than 3 million km² of watershed in nine countries. The Nile's freshwater flow into the southeastern Mediterranean Sea is interrupted by Egypt's Aswan High Dam, and seven other large dams on the Nile have reduced flow to the sea to miniscule proportions, which has fundamentally affected the ecology and fisheries of the eastern Mediterranean. In southeastern South America, 29 large dams, with several more being planned, are intended to control flow and provide electric power for economic growth of the Paraná River, which drains the Pantanal, a 2.5 million km² wetland that straddles four countries (Box 9.3, page 276).

The world's largest dam is under construction in China. The Yangtze River drains a 1.7 million km² watershed and empties into the East China Sea. This river already has 45 600 dams, large and small, and the

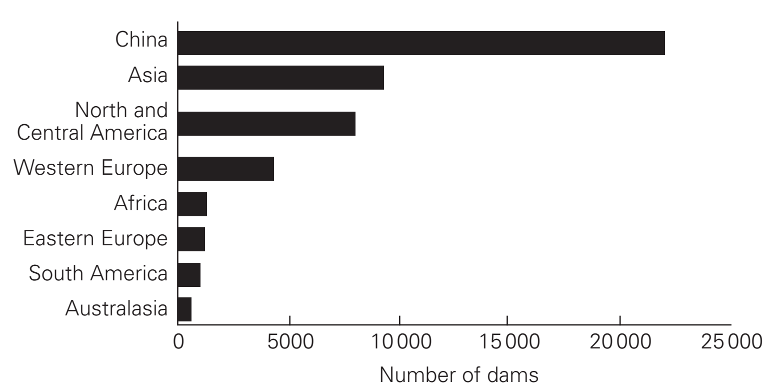

Fig. 1.7 Number and height of large dams worldwide. A large dam is one whose height is 15 m or higher, or whose height is between 10 and 15 m if it meets at least one of the following conditions: (i) a crest length of not less than 500 m; (ii) a spillway discharge potential of at least 2000 $m^3 s^{-1}$; or (iii) a reservoir volume of not less than 1 million m^3. From World Commission on Dams (2000), with permission.

Three Gorges Dam is to be the world's largest. The dam will be backed by a 690 km² reservoir with a maximum depth of 175 m. One major purpose is flood control, motivated by the death of 30 000 people after one of the worst Yangtze River floods, in 1954. The Three Gorges Dam is also intended for economic development and power generation. However, construction will displace more than a million people, and inundate many hectares of farmland. This dam will also affect valuable sea fisheries, habitats for rare fish, and the endangered white flag dolphin.

1.3.3.3 Urban land–seascapes

Productive coastal-marine areas are rapidly being physically transformed into commercialized urban complexes. A major contributor to this trend is that coastal environments satisfy cosmopolitan life-styles. The esthetic and recreational appeal of the ocean invites construction of hotels, marinas, residences, and condominiums on scenic coasts. Infrastructure and industry follow. Marina construction has rapidly increased worldwide to accommodate recreational boating and tourism, often with adverse effects on water quality. Canals and channels built to facilitate private boat uses cut into the land and create *cul de sacs* that alter hydrological patterns. In such areas, shores must be stabilized against erosive boat wakes, and canals must continually be dredged as a result of sedimentation. As tourism rapidly expands, huge docks are built to accommodate super cruise ships, some of which have been implicated in illegal dumping of wastes at sea. In many tropical nations, development has caused a general deterioration of local water quality, where sewage and construction wastes damage coral reefs and other productive environments. In the northern Mediterranean Sea, tourism and recreation may more than treble in the next few decades to further deplete already scarce resources and living space.

Tourism development is essential for many developing nations, but tourism places strains on limited water, land, and fisheries. Furthermore, tourism and leisure infrastructure often block local access to beaches and require constant maintenance against the forces of sea and storms. For more than a century, coastal engineers have attempted to fortify coastlines against erosion and storm damage and to protect human life and property by constructing groins, jetties, seawalls, and revetments, and by adding fill to eroding beaches. In some areas, bulldozers are continually deployed to reconstitute beaches after major storms (Fig. 1.8). Sophisticated engineering procedures can create a false sense of security that encourages overdevelopment and invites greater risks and costly shoreline defenses.

Fig. 1.8 Bulldozer restoring a beach at Scheveningen, the Netherlands, 1989. Photograph by the authors.

1.4 Tertiary issues

Tertiary issues are systemic and chronic, and are most difficult to address, as they relate directly to rates of change, irreversible conditions, and social values and norms, and thereby to difficult and controversial policies. These are poorly understood issues that focus attentions on complex interactions and difficult solutions.

1.4.1 Emergent phenomena

Emergent phenomena are not in history books, or publications, or recalled from memory or understanding. Presently, they are being widely reported, suggesting changes in environmental states or conditions that have occurred as a result of human interventions. Examples are many. Here, we consider only a few of the most notable.

1.4.1.1 Carcinogens and endocrine disrupters

Synthetic pollutants, once thought to be harmlessly dispersed and diluted in the environment, are causing new physiological disorders. Several synthetic compounds and pesticides are known for their persistence and for being endocrine disrupters, that is, chemicals that mimic hormones and alter biological functions such as reproduction. DDT, Kepone®, dioxins, PCBs, and others accumulate, persist, strongly associate with organic matter and sediments, and resist bacterial detoxification. DDT, long prohibited in many parts of the world, still occurs in sea life. PCBs also remain widespread in the environment, from tropical to polar regions. These and other compounds can bioaccumulate through food chains to pose potential health hazards to coastal-marine and human life. Many are known carcinogens that concentrate in organisms and can be metabolized into more toxic forms.

Many studies indicate effects of endocrine disrupters on reproduction, for example: juvenile male otters (*Lutra canadensis*) in the Columbia River with reduced penis size; male Western gulls (*Larus occidentalis*) with feminized behavior; male Florida panthers (*Felis concolor*) whose testicles failed to descend; male American alligators (*Alligator mississippiensis*) in Florida with nonfunctional testes; and masculinized female mosquito fish (*Gambusia affinis*). In the Baltic Sea, populations of gray seals (*Halichoerus grypus*) and ringed seals (*Phoca hispida*) have exhibited low fertility rates correlated with PCBs in their tissues. In the polluted portion of the Baltic, cod, salmon, and sea trout have shown poor recruitment. There is also evidence of endocrine disruption in common carp (*Cyprinus carpio*) and largemouth bass (*Micropterus salmoides*) in freshwaters that contain synthetic organic compounds. These effects have the potential to occur in humans.

1.4.1.2 Harmful algal blooms

Many species of single-celled algae live in the sea. Most are beneficial, serving as energy producers at the base of the food web. Occasionally they "bloom" and accumulate into dense patches. Such blooms have been recorded throughout history. What may be new is their proliferation and new forms. Harmful algal blooms that contain toxins or cause other negative effects are becoming common occurrences that affect natural communities by replacing species, shading vegetation, disrupting food-web dynamics, and causing oxygen depletion. Some blooms concern public health when toxins enter food webs to concentrate in species consumed by humans. Globally, several thousand cases of human poisoning are reported each year from consumption of fish or shellfish that have consumed toxic algae.

A microscopic benthic dinoflagellate is known to cause human ciguatera poisoning when fish are consumed that contain its toxin. Captain Cook suffered from ciguatera when visiting New Caledonia in 1774. Today, ciguatera is responsible for more cases of human illness than any other kind of seafood toxicity. In 1960–84, more than 24 000 cases of human poisoning were reported from French Polynesia alone, more than six times the average for the Pacific as a whole.

A highly toxic dinoflagellate (*Pfiesteria piscicida*) has recently been discovered on the United States east coast. The cause for its appearance is not known and many questions remain about its natural history. Apparently, its two dozen life-history stages exhibit both animal and alga characteristics, allowing it to change habits, depending on circumstances. *Pfiesteria* is able to photosynthesize, but becomes a predator when fish are present. In its killing stage, *Pfiesteria* releases a neurotoxin that stuns the fish and facilitates consumption of the flesh. *Pfiesteria* is implicated in fish kills, organic pollution, and severe human ailments.

1.4.1.3 Anoxic bottom water

Low oxygen concentration (hypoxia) is characteristic of some deep-ocean waters. When hypoxic waters become anoxic (lacking oxygen) the result is a "dead zone," and all organisms that require dissolved oxygen perish. Hypoxic conditions are exacerbated by human activities, such as fertilizers from farms and lawns, and appear to be increasing in coastal and estuarine areas worldwide (Fig. 1.9).

A prominent example of a hypoxic zone occurs annually in the northern Gulf of Mexico. Hypoxic water was first observed off Louisiana–Texas shores during the mid-1970s, probably due to nutrient enrichment from the Mississippi and Atchafalaya rivers. By summer 1989, hypoxia extended over 9000 km^2 of the inner continental shelf. Recently, hypoxia has cut a lethal swath through about 18 000 km^2 of these coastal waters. Hypoxia–anoxia also occurs in Chesapeake Bay during summer months, when deep waters become nearly devoid of life. On New Jersey's continental shelf, localized oxygen depletion occurred in 1968, 1971, and 1974; in 1976, severe oxygen depletion began in July and persisted until October, creating an oxygen-depleted corridor 5–85 km offshore and extending 165 km southward to cover 12 000 km^2. The Black Sea is naturally anoxic below its halocline; this condition has been increasing, causing massive mortality of demersal fishes. The Baltic and Mediterranean seas also appear to be on long-term trends toward anoxia, should current trends of urbanization and pollution continue.

1.4.1.4 Mass mortalities, epidemics, and pandemics

Many diseases now afflict coastal-marine organisms in epidemic proportions (Table 1.11). Whether these

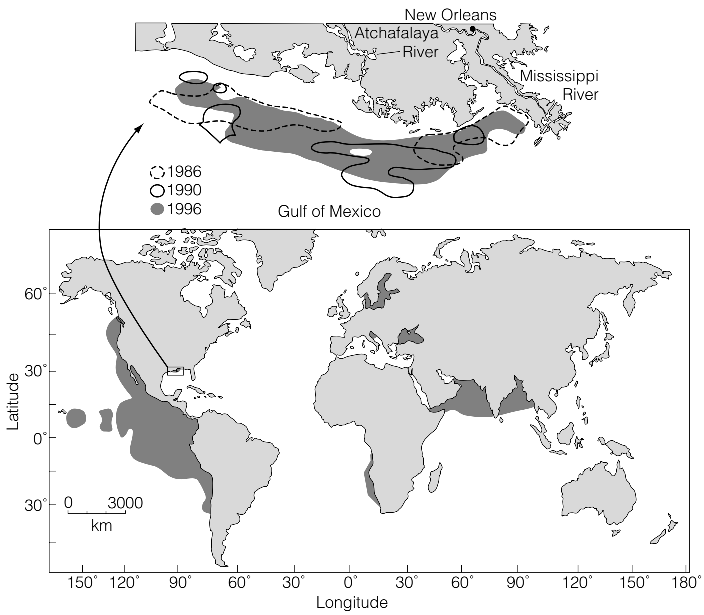

Fig. 1.9 Areas of the world experiencing marine hypoxia. *Lower figure*: portions of the Pacific and Indian oceans have lower dissolved oxygen concentrations and greater areas exposed to hypoxia than the Atlantic. These conditions may have existed for long periods of time. Hypoxia has been exacerbated in several other areas, e.g., the Black Sea, due to human activities. From Diaz & Rosenberg (1995), with permission from R.N. Gibson. *Upper figure*: northern Gulf of Mexico "dead zone" encompassing different areas of shelf water in recent summers. This seems to be a new condition, probably caused by increased nutrient inputs from the Mississippi and Atchafalaya rivers. From Ferber (2001), with permission from N. Rabalais.

are new or re-emergent is difficult to determine. In 1931–2, North Atlantic eelgrass (*Zostera marina*) was struck by a "wasting disease" caused by a slime mold (*Labyrinthula macrocystis*), which extirpated eelgrass in many areas. Eelgrass has returned to many areas, but complete recovery has not yet occurred. In the Caribbean Sea, a sea fan (*Gorgonia ventalina*) has been infected by a fungus (*Aspergillus sydowii*), evidently carried on airborne dust from Africa (page 239). On Florida reefs in June 1995, some 16 species of corals and a hydrocoral bore symptoms of an unusual coral disease – a readily transmissible, virulent bacterium (*Sphingomonas*) first described in 1990. In the 1980s, abundant Caribbean sea urchins (*Diadema antillarum*) that graze algae on reefs suddenly became rare due to disease. Such repeated, severe infestations have the potential to restructure reef communities.

In 1987, many freshwater Baikal seals (*Phoca siberica*) died from canine distemper. Forms of phocine distemper virus (PDV) killed approximately 25 000 North Sea harbor seals (*Phoca vitulina*) in 1988, after which the population recovered, only to experience large die-offs from PDV in 2002. Viruses have also caused mortalities among striped dolphins (*Stenella coeruleoalba*) and endangered Mediterranean monk seals (*Monachus monachus*). Fin whales (*Balaenoptera physalus*) have been reported with morbillivirus infection. In 1998, more than 1600 New Zealand sea lion pups (*Phocarctos hookeri*) died at Auckland Island during a bloom of toxic algae. Viral infections and pollutants also have been implicated in the deaths of more than 700 bottlenose dolphins (*Tursiops truncatus*) in 1987–8 off U.S. mid-Atlantic shores and in excess of 500 harbor seals in New England waters in 1979–80. Pollutants may increase susceptibility of marine mammals to infections by reducing immunity.

A host of diseases also occur in invertebrates, fishes, and marine reptiles, seabirds, and mammals in which populations are reduced and reproductive fitness is altered. Humans also face diseases caused by marine pathogens, for example cholera (*Vibrio cholerae*). This deadly disease is associated with consumption of contaminated shellfish and widespread problems of sewage treatment and water quality. Ships' ballast water can carry the pathogen and some species of plankton can act as hosts for dormant bacteria. In January 1991, residents of a town near Lima, Peru, suffered from a virulent Asiatic strain, perhaps introduced by an Asian freighter anchored in the harbor. The pathogen quickly spread to other South American and Central American countries. By the end of 1991, more than 3000 Peruvians and more than 1000 people from other countries had died. In 1992, a new form of the pathogen was identified in ten Asian nations. By February 1993, Brazil had become the focus of infection, with 32 313 cases and 389 deaths. By December 1993, Latin

Table 1.11 Selected examples of marine diseases associated with mass mortalities, defined as > 10% mortality within a population or group. Taxa that suffered mortality are listed under Biota; their location listed by Ocean/sea.

Group/Location	1930s	1940s	1950s	1960s	1970s	1980s	1990s
Biota							
Kelp							•
Red algae							•
Sea grass	•					•	
Sponge	•						
Coral						•	•
Clams						•	
Scallops						•	
Abalone						•	
Oysters		•		•	•	•	
Starfish					•		
Sea urchins						•	•
Fish			•				•
Seals			•			•	
Cetacea						•	•
Ocean/sea							
North Atlantic	•			•	•	•	
Northeast Atlantic					•		
Gulf of St. Lawrence			•				
North Europe	•					•	•
Mediterranean							•
Gulf of Mexico, USA		•					
North Caribbean	•						
Caribbean						•	
West Caribbean						•	
North Pacific							•
Northeast Pacific					•		
South Pacific							•
Lake Baikal							•
Australia							•
Antarctica			•				
Southern Ocean							•

Adapted from Harvell et al. (1999).

America and the Caribbean had experienced 700 000 cases and 6400 deaths.

1.4.2 Altered communities and ecosystems

Community and ecosystem change comprise the most far-reaching issue facing conservation, for they incorporate all other issues and are often associated with unpredictable and unexpected outcomes, including the emergent phenomena described above. Dramatic changes in biotic communities have occurred during the past several centuries, mostly because of human-initiated resource exploitation and physical alterations. Such changes go far beyond direct influences, affecting global chemical cycles and climate, and dramatically accelerated during the 20th century. Most scientists now concur that chemical cycles and climate continue to change on a global scale. Uncertainty remains about cause or direction, that is, to what extent human activities are a cause, where nutrients may be sequestered, or even whether global warming or cooling may result. One major problem is that only short-term changes are amenable to direct study. Longer time scales of change can be derived only from retrospective studies during hundreds to thousands of years. Nevertheless, as research continues, anthropogenic activities are ever more implicated.

One type of ecosystem change that may be occurring at the hands of humans concerns global biogeochemistry. Life on Earth is based on cycles of carbon, nitrogen, and phosphorus, among others. Carbon dioxide (CO_2)

Fig. 1.10 Baltimore Harbor is a major U.S. port and industrial location, representing the transformation of a subestuary of Chesapeake Bay into a conurbation. Photograph by the authors.

is especially critical as it is essential for photosynthesis, the basis for most life on Earth. The flux of CO_2 across the air–sea interface seems to be the greatest influence on the global carbon cycle. Fossil fuel combustion today adds billions of tons of CO_2 to the atmosphere annually, mostly from economically developed regions of temperate zones. This input has poorly understood effects on coastal-marine life. Alteration of the global nitrogen cycle also has consequences for ocean systems. Total net human nitrogen inputs to rivers and oceans amounts to many million tons per year. Such massive inputs have the potential to alter the nitrogen cycle.

Another major ecosystem alteration concerns watersheds, which act as Earth's arterial systems by delivering freshwater, materials, and nutrients that help sustain coastal-marine ecosystems. Freshwater is rapidly becoming Earth's most endangered resource. Only about 0.26% of global freshwater is available for human consumption. As demand increases, overdrafting is occurring in most parts of the world. This situation is made complex because water flows across jurisdictions, overland and underground, and uneven distributions are among the most acute and complex of social problems. The combined effects of construction of dams and reservoirs, natural water supply variations, water diversions, land use change, groundwater withdrawal, shoreline erosion, and saltwater intrusion all result in significant changes of coastal ecosystems, their productivity, and their biotic communities.

1.5 Conclusion

All the issues related above have roots in complex natural processes and are exacerbated by human activities to some extent. They are best viewed through the lens of human social trends, rates of change, and momentum – for example, population, consumption, technology, and efforts to increase human wellbeing. Tertiary issues are most difficult for human institutions to address, and require an ecosystem perspective. This is especially the case in the coastal realm, where most of the human population resides and where cities are spreading into conurbations (Fig. 1.10). World population reached six billion on October 12, 1999. About 60% of this population is concentrated within 100 km of coasts. In the future, higher rates of population increase are projected for coastal areas than inland. And, as coastal populations and cities expand, demands for resources expand exponentially. One major consequence is that the most productive areas for humans on Earth – estuaries, lagoons, deltas, and the coastal ocean – are being transformed into urban space or are becoming dominated by human activities, with consequences that can be difficult to predict.

Succeeding chapters will illustrate mechanisms for addressing current coastal-marine issues, the minimum knowledge base that must be attained, how the nature of change itself may be understood, and how the environmental debt may be confronted.